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PHOSPHORUS REMOVAL AND PLANT OPERATION STUDIES AT FORT WAYNE, INDIANA

Paul L. Brunner, et al

Fort Wayne Water Pollution Control Plant

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PHOSPHORUS REMOVAL AND PLANT OPERATION STUDIES AT FORT WAYNE, INDIANA

by

Paul L. Brunner
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City of Fort Wayne
Fort Wayne, Indiana 46802

Grant #11060 DXX

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16. Abstract

The demonstration project at the Fort Wayne, Indiana Wastewater Treatment Plant showed that the addition of a portion of the spent lime sludge from the City's water conditioning plant to the influent to the aeration tanks would slightly increase the normal capacity of the activated sludge to remove phosphorus. The same addition, 31,500 to 35,500 pounds per day of spent lime sludge solids, prevented sludge bulking during the warmer months of the year when poor settling sludge is experienced.

Duplicate pilot plants were evaluated for the removal of phosphorus by luxury uptake and acid elutriation and as a conventional activated sludge unit. Removals in both units were comparable to those attained in the full scale plant. Higher phosphorus removals were achieved when chemicals (lime, ferric chloride, polyelectrolytes, pickling acid) were used singly or in combination in the pilot plants.

A survey of the flow and characteristics of the sewage in various locations in the City demonstrated that the concentration of total and soluble phosphorus varies with location and, therefore, can to some extent be controlled.

Preliminary studies with a tertiary treatment pond receiving treatment plant effluent and storm water overflow indicate that BOD_5 and suspended solids concentrations are substantially reduced during passage through the pond (EPA)

This report was submitted by the City of Fort Wayne, Indiana, in fulfillment of Grant No. 11060 DXX under the partial sponsorship of the Water Environmental Protection Agency.

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*Indiana, Phosphorus, Treatment facilities, Water softening, Lime.

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ABSTRACT

The demonstration project at the Fort Wayne, Indiana Wastewater Treatment Plant showed that the addition of a portion of the spent lime sludge from the City's water conditioning plant to the influent to the aeration tanks would slightly increase the normal capacity of the activated sludge to remove phosphorus. The same addition, 31,500 to 35,500 pounds per day of spent lime sludge solids, prevented sludge bulking during the warmer months of the year when poor settling sludge is experienced.

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SECTION I

CONCLUSIONS

1. The spent lime sludge from a water conditioning plant when processed in an activated sludge plant will increase the phosphorus removal slightly over that obtained by a conventional activated sludge plant operating under the conditions similar to those experienced at Fort Wayne.

2. Phosphorus incorporated in activated sludge in the Fort Wayne Wastewater Treatment Plant is not removed from the sludge by elutriation after acidification.

3. Additions of lime, polyelectrolytes, ferric chloride, and pickling acid singly or in particular combinations will increase the removal of phosphorus in an activated sludge plant appreciably over the removal attained with activated sludge alone.

4. Jar tests with lime, ferric chloride, and NALCO 676 in various quantities and combinations show that, under ideal conditions, phosphorus removals as high as 99 percent can be attained.

5. The quantity of phosphorus in a wastewater collection system is not equally distributed.

6. Activated sludge that has a tendancy to bulk can be controlled with spent lime sludge from a water conditioning plant by dosing the lime sludge to the influent to the aeration tanks.

7. Sludge bulking was appreciably reduced by addition of primary sludge to an aeration tank.

8. A short detention tertiary treatment pond significantly upgraded effluent from the City's activated sludge plant reducing residual BOD_5 by about 50 percent and residual suspended solids by 40-80 percent. Attention is directed to the fact that the data represents a period of short duration in a pond placed in operation during the data collection time frame. The reader is cautioned to evaluate this conclusion accordingly.

SECTION II

RECOMMENDATIONS

Determine the optimum quantity of spent lime sludge essential for bulking control of activated sludge at Fort Wayne.

First stabilize operation of pilot plants to control bulking and once bulking is under control then undertake studies to determine luxury uptake.

Conduct pilot plant scale tests to determine the chemical dosages required to provide an 80 percent removal of phosphorus in primary treatment.

Determine the cost of recirculation of large quantities of spent lime sludge in the aeration and sludge digestion processes in the Fort Wayne Wastewater Treatment Plant.

Investigate the behavior of nitrogen, phosphorus and bacteria in the tertiary pond while it serves to retain storm water and provide tertiary treatment of activated sludge plant effluent.

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SECTION III

INTRODUCTION

The Indiana Stream Pollution Control Board has indicated that phosphorus removal facilities will be required for the City of Fort Wayne, Indiana. Consequently, a major part of this grant project was devoted to evaluating methods of phosphorus removal in the City's activated sludge plant and in a pilot plant constructed for the purpose. In addition, the effects of brewing wastes from local breweries and spent lime sludge from the City's water conditioning plant on the settleability of activated sludge were studied. Also studied was the possibility of using electrolytic flotation as an aid in wastewater treatment. Lastly, preliminary studies on the tertiary pond treatment of the activated sludge plant effluent were conducted.

In regard to the bulking of activated sludge, Fair, et al (1) reported that masses of filamentous bacterium Sphaerotilus are often associated with bulked sludge and that high carbohydrate levels appear to promote its growth. Pipes (16) reported the presence of large numbers of Sphaerotilus in the Fort Wayne activated sludge during periods of sludge bulking.

Despite considerable space devoted to it in literature in recent years, the exact mechanisms involved in so called luxury or biological phosphorus removal are not known. Duplication of the high removals observed at San Antonio, Baltimore, and Hyperion has not been readily accomplished at other plants. The most important observation made in the literature is that plug flow is required. Every plant successfully removing phosphorus is built to achieve plug flow. This is typically done in long narrow aeration basins frequently baffled to prevent short circuiting. The uptake of phosphorus occurs chiefly during the interval when the substrate food level is low. In contrast, in a complete mix system the same food level exists throughout the aeration unit and in the effluent. Thus, the organisms are never subject to a low food stress situation and are reported not to accumulate excess phosphorus.

Milbury (2) has shown that luxury phosphorus removal is also dependent on adequate aeration. In his work, repeated cyclic variation of removed phosphorus was related to changing dissolved oxygen in the system. Numerous investigators (2) (12) (6) have reported that it is necessary to maintain more than 1 mg/l dissolved oxygen in the last half of the aeration basin for reliable biological phosphorus removal. Some evidence shows that excessive or prolonged aeration tends to cause auto oxidation of the organisms with resultant phosphorus release from the cells. Milbury (2) also reports a release of phosphorus from the return sludge at the head end of the aeration tank before uptake occurs. This results in much greater phosphate levels than contained in the influent waste alone, but they are consistently removed by the process. Little adsorbed

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phosphorus is released to the effluent during settling in the final clarifier if the sludge level is kept reasonably low in the clarifier. To achieve this, a continuous removal of waste sludge at a low rate has been found effective at Baltimore, while at San Antonio polyelectrolytes have been added to improve settling of the sludge. Connel and Vacker (3) observe that once separated, the phosphorus should not be allowed to re-enter the process stream.

Growth of new sludge in the aerator must occur rapidly and in large enough quantity to utilize the available phosphorus. The ratio of BOD to PO_4 is an indicator of wastewater composition. Connell and Vacker (3) have shown that if this ratio falls below 6:1, phosphorus removal is hampered. There appears to be no optimum ratio as good removals have been observed with ratios as high as 11:1. If the wastewater is deficient in soluble BOD, poor results may occur even if the total BOD appears adequate. Raw wastewater from Whittier, California displayed this phenomenon and only when sugar was added (200 mg/1) was any phosphorus removed. The addition of sugar produced a 57 percent reduction of phosphorus at this plant.

One theory on biological luxury phosphorus uptake is that the phenomenon is not due to biological activity (15) at all. Instead, it is proposed that the rapid aeration in the latter portion of an aeration tank may cause a pH shift due to carbon dioxide stripping of the wastewater which in turn results in precipitation of phosphorus as hydroxyapetite. Precipitation of phosphorus with metallic salts contained in the wastewater also is suggested as a partial explanation for the apparent removal by luxury biological uptake.

SECTION IV

OBJECTIVES

There were numerous objectives to be attained in this study briefly outlined as follows:

1. To study the operation of the Fort Wayne Wastewater Treatment Plant, with modifications, for phosphorus removal by activated sludge in pilot plant and full-scale units.

2. To study economical and feasible methods of phosphorus reduction in the pilot plant.

3. To study the thickening of activated sludge solids by the electrolysis floatation, separation densification process.

4. To study the treatment efficiency and effects of tertiary pond treatment for phosphorus removal in a full-scale unit.

5. To study the causes, effects, and control of activated sludge bulking in pilot plant and full-scale units.

6. To study the effects of brewing wastes on wastewater treatment and sludge bulking in pilot plant and full-scale units.

7. To study the effects of spent lime sludge from a water treatment plant on the settling of activated sludge in pilot plant and full-scale units.

8. To study the discharge of spent lime sludge to an activated sludge plant as a means of lime sludge disposal in pilot plant and full-scale units.

9. To study the effects of potato chip, cresylic acid, brewing, plating, starch, and acid wastes together with limited and expected portions of domestic waste on the operation of the activated sludge process.

10. To study the separation of activated sludge mixed liquor by electrolytic flotation and gravity separation in a pilot plant.

SECTION V

FACILITIES FOR THE RESEARCH

DESCRIPTION OF THE WASTEWATER TREATMENT PLANT

The Fort Wayne Wastewater Treatment Plant consists of primary treatment with separate sludge digestion, followed by activated sludge secondary treatment. Wastewater enters the plant 32 ft. below grade through a 7 ft. semi-elliptical sewer. There is a bypass located on the Wayne Street interceptor approximately 300 ft. west of the plant. Storm water and sewage in excess of plant capacity may be automatically bypassed to the Maumee River through an 84-inch sewer.

The wastewater flow is divided between two 7 ft. wide by 60 ft. long grit chambers equipped with hydraulically operated sluice gates at each end. Wastewater entrance velocity is 2 ft. per second and grit chamber velocity is 1 ft. per second. Wastewater then passes through 3/4-inch mechanically raked bar screens with rakings ground and returned to the wastewater. Grit is removed by mechanical scrapers to a sump and pumped to a lagoon where the grit is settled out. Lagoon effluent is returned to the plant for treatment.

Four three-speed automatic float controlled wastewater pumps and one 10-20 MGD gas engine driven wastewater pump with variable speed flow control provide 70 MGD total plant pump capacity. The four pumps are operated by 125 HP electric motors. The pump engine will operate during power failures. These pumps lift the wastewater 32 ft. from the wet well to the raw wastewater trough.

The primary tanks have a total volume of 2,210,000 gallons. There are rotary scum troughs on all primary tanks. Raw sludge is removed by mechanical scrapers and flows by gravity and manual controlled air lifts to a sludge pit. It is then pumped to the primary digesters along with the scum.

There are five two-bay aeration tanks. The volume of each bay is 1,050,000 gallons, yielding a total volume of 10,500,000 gallons. The average detention with 30 percent sludge return is 6.2 hours. Three of the tanks are equipped with diffuser plates. A fourth tank is equipped with ceramic diffuser tubes on swing type headers, and the fifth tank is equipped with saran precision diffuser tubes on swing type headers. The wasted activated sludge flows by gravity to the wet well and the sludge pit.

There are five 110 ft. diameter center feed final settling tanks. The total volume of the final tanks is 5,000,000 gallons. The average detention time with 30 percent return sludge is 2.6 hours. The tanks are equipped with revolving sludge removing mechanisms (Tow-Bro sludge collectors). The final effluent flows over V notched weirs, is metered, and discharged ot the Maumee River. Activated sludge is returned to the aeration tanks by air lift pumps. The final tanks have air bubbler type sludge blanket level indicators.

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There are six 90 ft. diameter digesters, 29 ft. deep at the side wall with an additional 6 ft. deep cone. Two of the digesters are used as primary digesters and four as secondary digesters. All digesters are equipped with floating covers, leaving 26 ft.-6-inch effective depth. The total volume of the digesters is 1,094,000 cu. ft. or 8,210,000 gallons. The tanks are equipped with gas, supernatant, and sludge take off lines. The secondary digesters have internal periphery hot water heating coils.

The sludge going to the two primary digesters is heated in two sludge heaters. The heating source is circulating water from the gas engines and an auxiliary boiler.

Gas is removed from the digesters, purified, and used as fuel for the gas engines and boilers. Excess gas is compressed by two motor driven compressors and stored in spherical holders at 35-pounds pressure. The 32 ft. diameter holder has a capacity of 40,000 cu. ft.; the 45 ft. diameter holder has a capacity of 110,000 cu. ft. Waste gas is burned in the waste gas burner.

The control building houses, in addition to the raw wastewater pumps, one dual-fuel engine driven blower with capacity of 7,000 CFM, two 7,000 CFM blowers driven by 350 HP electric motors, and one 465 HP gas engine and blower of 11,000 CFM capacity. This building also includes a control room, raw sludge diversion pit and pumps, hot water circulating pumps, air blower piping, air filters, office, laboratory, and boiler room. A unique ventilating system discharges air to the intake of the blowers and is then diffused into the aeration tanks. An eight station automatic explosive gas alarm system is located in the control room.

The aeration building houses settled wastewater piping and control valves, return and waste activated sludge controls, air piping, a control panel with meter equipped for remote operation of valves. Also provided are steam unit heaters, full blower ventilation, and a central collection point for all individual secondary plant samples.

The digester building houses gas compressors, sludge and supernatant pumps, piping, meters, a dual-fuel boiler, two sludge heaters, and a tunnel to the main control building to carry process piping and conduit. A four station automatic explosive gas alarm system is located in this building. The waste gas burner is mounted above the roof.

Digested sludge is handled by employing the shallow lagoon method of drying and then it is removed with mechanical equipment and given away as a soil conditioner. Lagoons are located at two separate areas. The first five lagoons of approximately 200,000 cu. yd. liquid capacity are 3,500 ft. east of the plant. The second and newer area is two and a half miles east of the plant and has a total land area of 200 acres, 66 of which are in lagoons with a liquid capacity of 530,000 cu. yd.

A schematic diagram of the wastewater treatment plant is shown in Figure 1.

DESCRIPTION OF THE PILOT PLANT

A 10 gpm steel pilot plant, comprising duplex tankage for gravity primary settling, aeration, secondary gravity settling, acid mixing for separated activated sludge, elutriation for phosphorus stripping, and phosphorus-free sludge separation for return to aeration, is shown in the photograph and isometrically in Figure 2. Separation and densification of activated sludge from the aeration tank mixed liquor was provided for, in parallel with gravity separation, by Chicago Pump's Electrolytic Flotation Separation-Densification System in a dual unit of 10 gpm capacity. Likewise, another flotation unit of 10 gpm capacity was provided for concentrating the desorbed phosphates from the acidified activated sludge and separating the phosphate free activated sludge for return to the aeration tank. Figure 3 shows the relation of the Pilot Plant to the full-scale treatment works.

DESCRIPTION OF FACILITIES FOR SPENT LIME SLUDGE UTILIZATION

A pipeline for the delivery of spent lime sludge from the City water conditioning plant to the wastewater treatment plant was installed to dose spent lime sludge to the primary settling tanks or any one or all of the five aeration tanks. A schematic diagram of the piping for the lime sludge is shown in Figure 4.

DESCRIPTION OF FACILITIES FOR EVALUATING INDUSTRIAL WASTES

A pipeline for transporting brewery wastes to the wastewater treatment plant for use in the pilot plant and full-scale facilities is shown schematically in Figure 5. A 5,000 gallon tank truck was available for transporting particular industrial wastes to the pilot plant for testing as shown in Figure 6 but this unit was not required.

DESCRIPTION OF THE TERTIARY TREATMENT POND

Construction of a chlorination contact tank followed by a tertiary pond was substantially completed during this demonstration. Initial operations were included in the data collection time frame.

The tertiary treatment pond is 40 acres in area and holds 50 million gallons at the 5 ft. level and 150 million gallons at the 13 ft. (storm) level. The dikes which impound the water range in height from 8 to 12 ft. above original gound and have an impervious clay core which is 2 ft. below the elevation of the original ground. The location of the pond in relation to the wastewater treatment plant is shown in Figure No. 7.

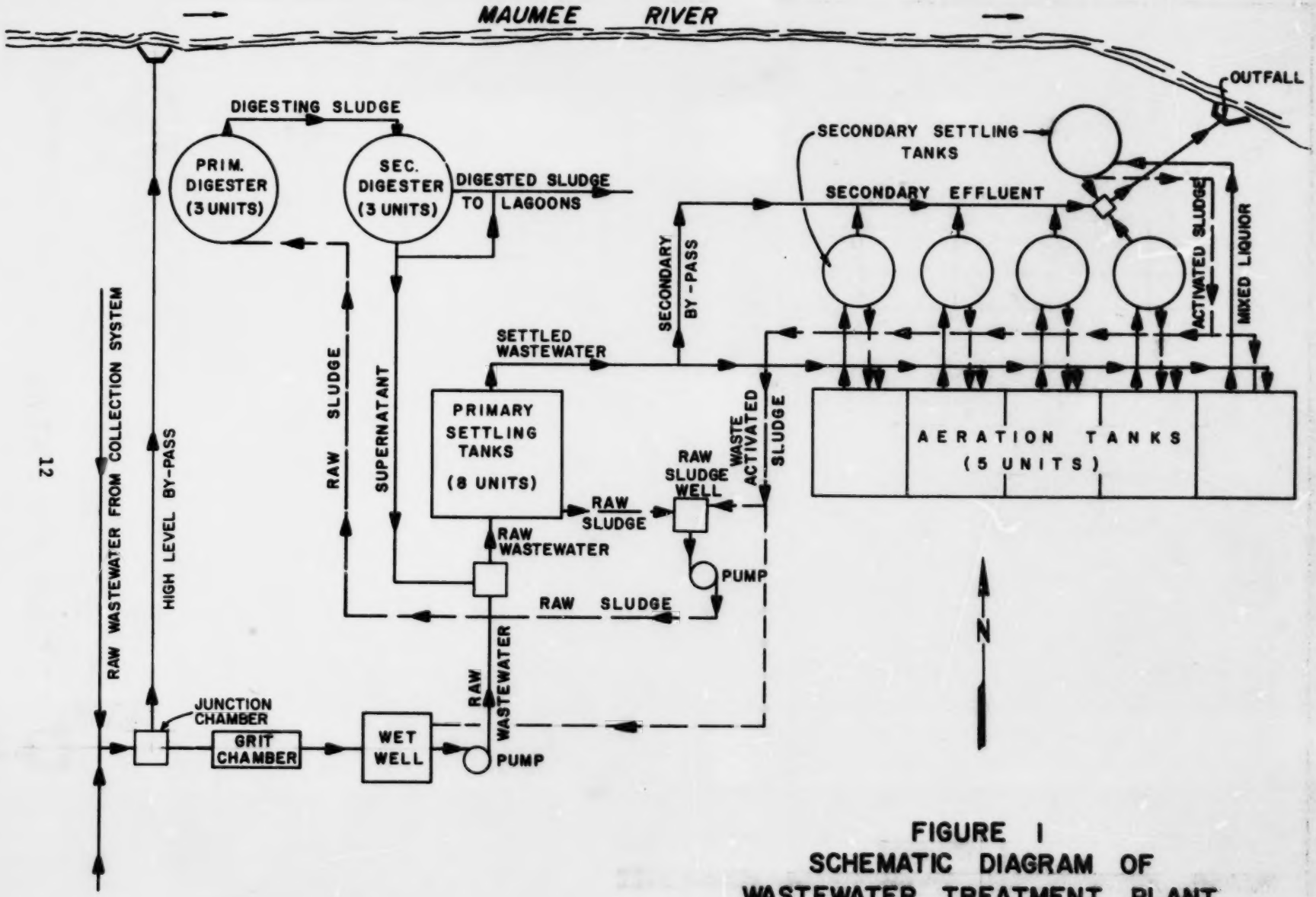
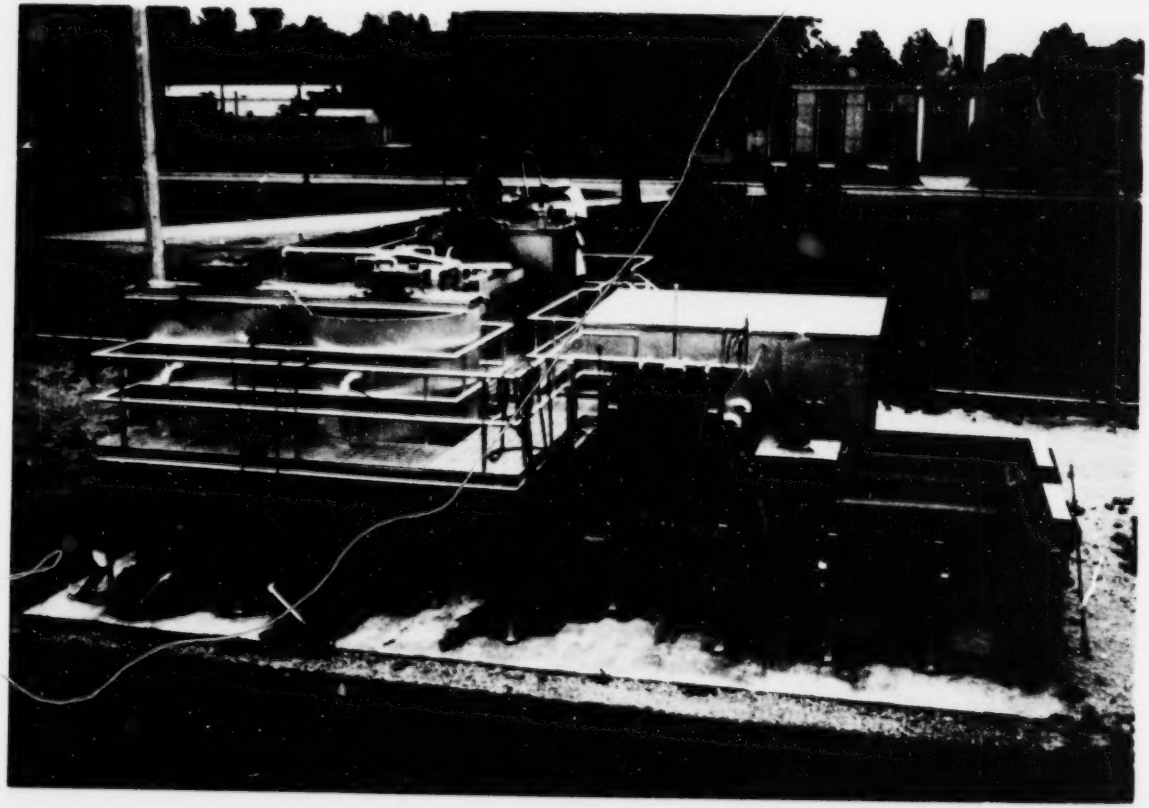


FIGURE I
SCHEMATIC DIAGRAM OF
WASTEWATER TREATMENT PLANT
SHOWING EXISTING FLOW PATTERN



PHOTOGRAPH NO. 1

PHOSPHATE REMOVAL PILOT PLANT

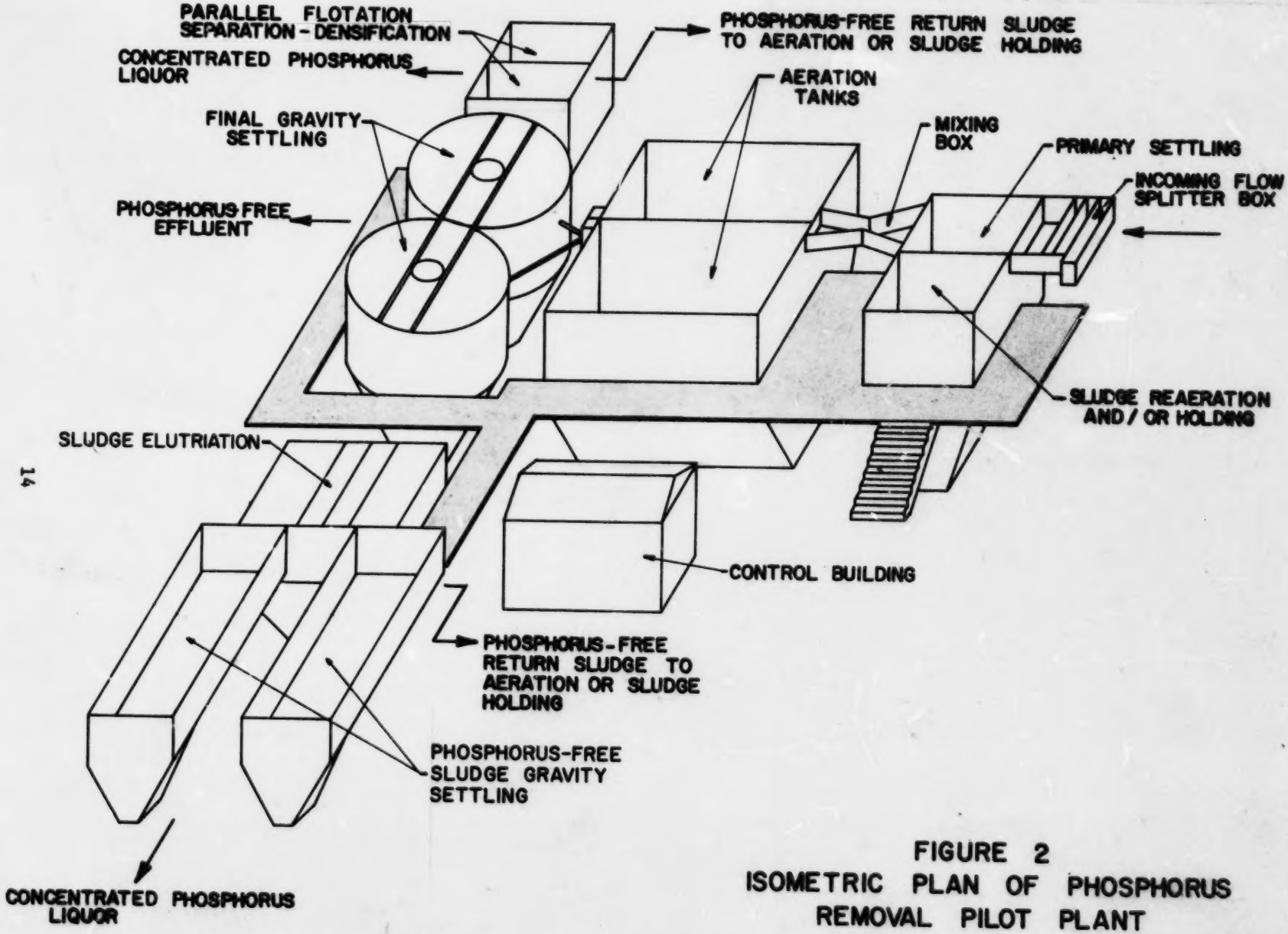


FIGURE 2
ISOMETRIC PLAN OF PHOSPHORUS REMOVAL PILOT PLANT

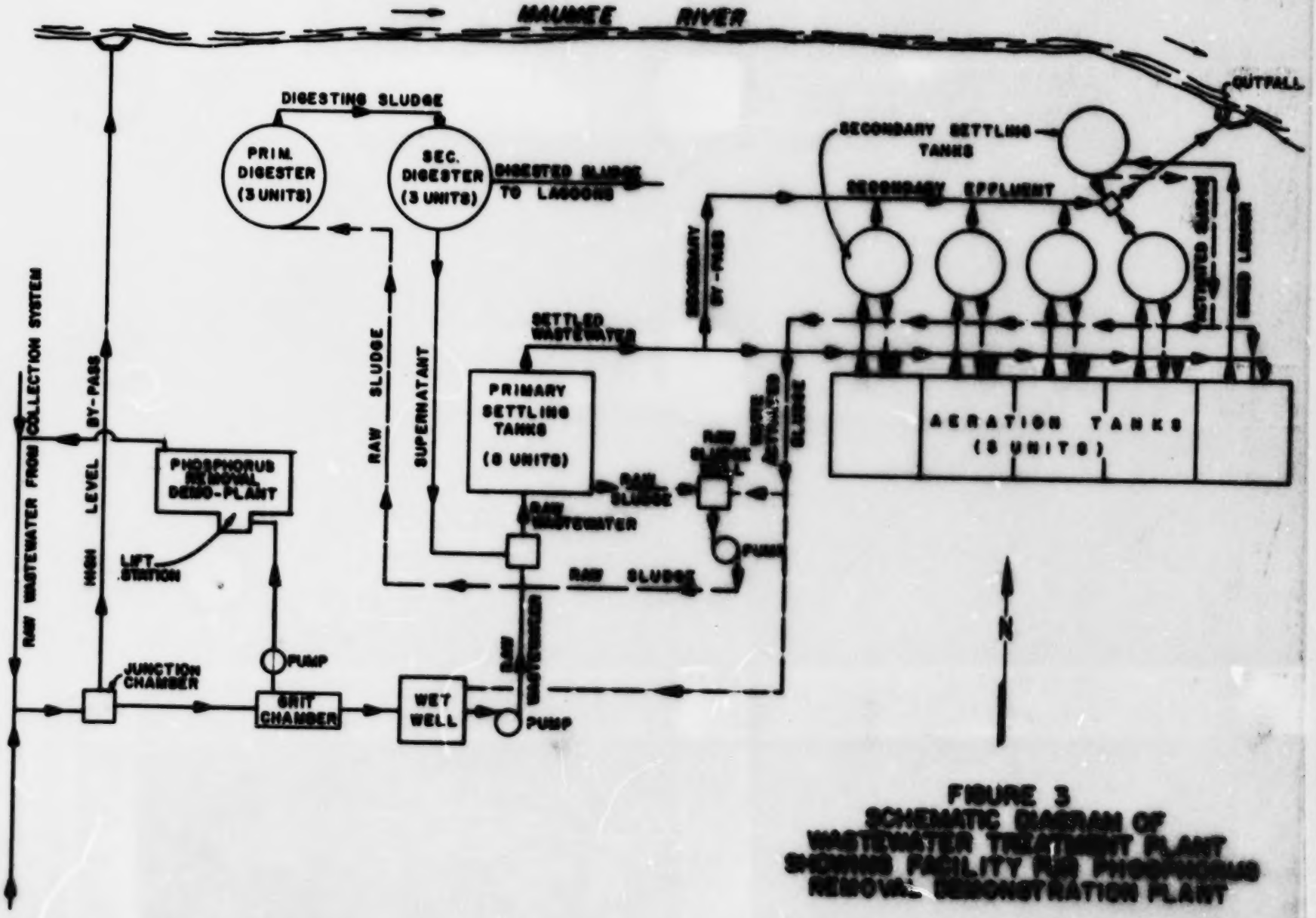


FIGURE 3
SCHEMATIC DIAGRAM OF WASTEWATER TREATMENT PLANT SHOWING FACILITY FOR PHOSPHORUS REMOVAL DEMONSTRATION PLANT

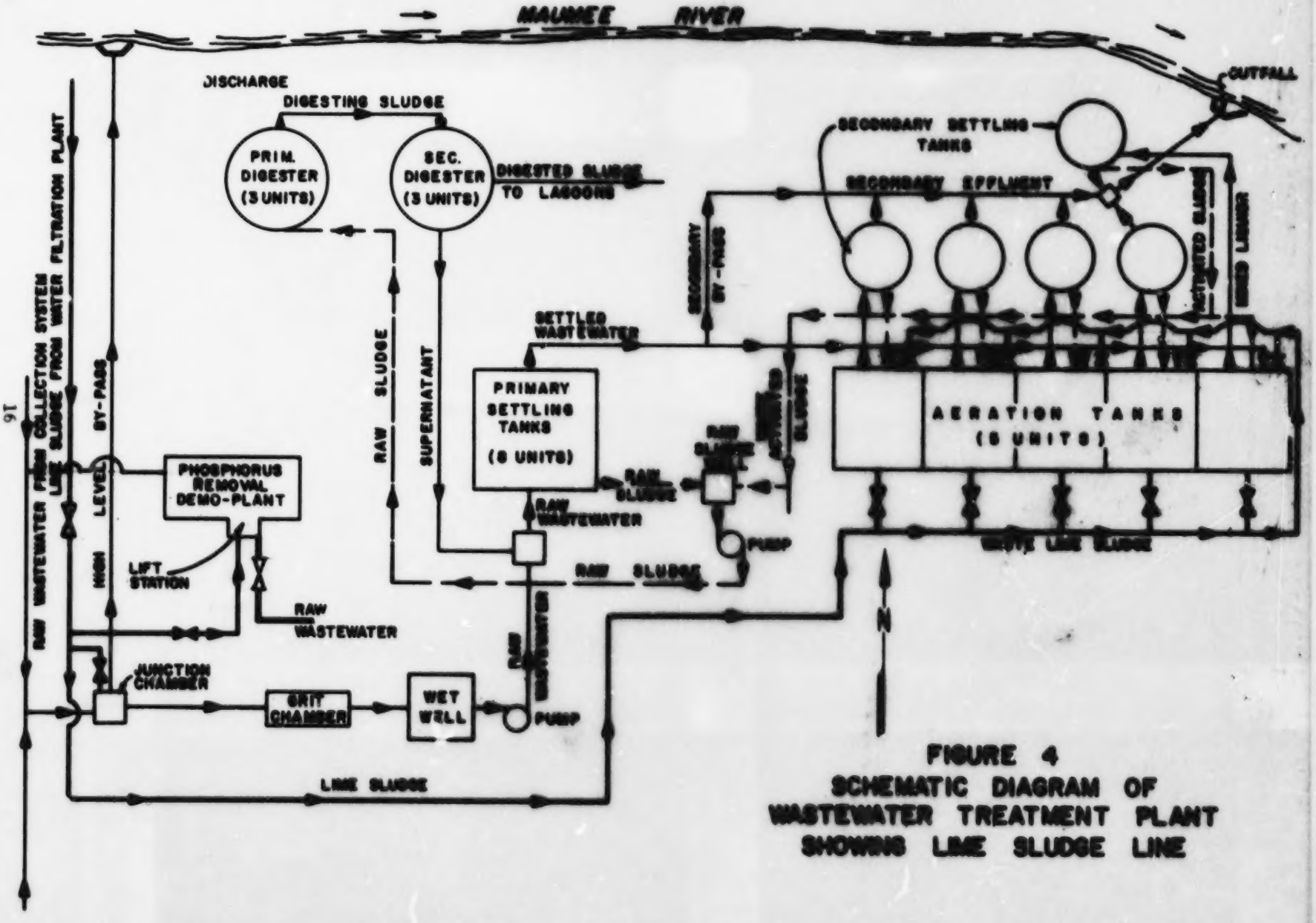


FIGURE 4
SCHEMATIC DIAGRAM OF
WASTEWATER TREATMENT PLANT
SHOWING LIME SLUDGE LINE

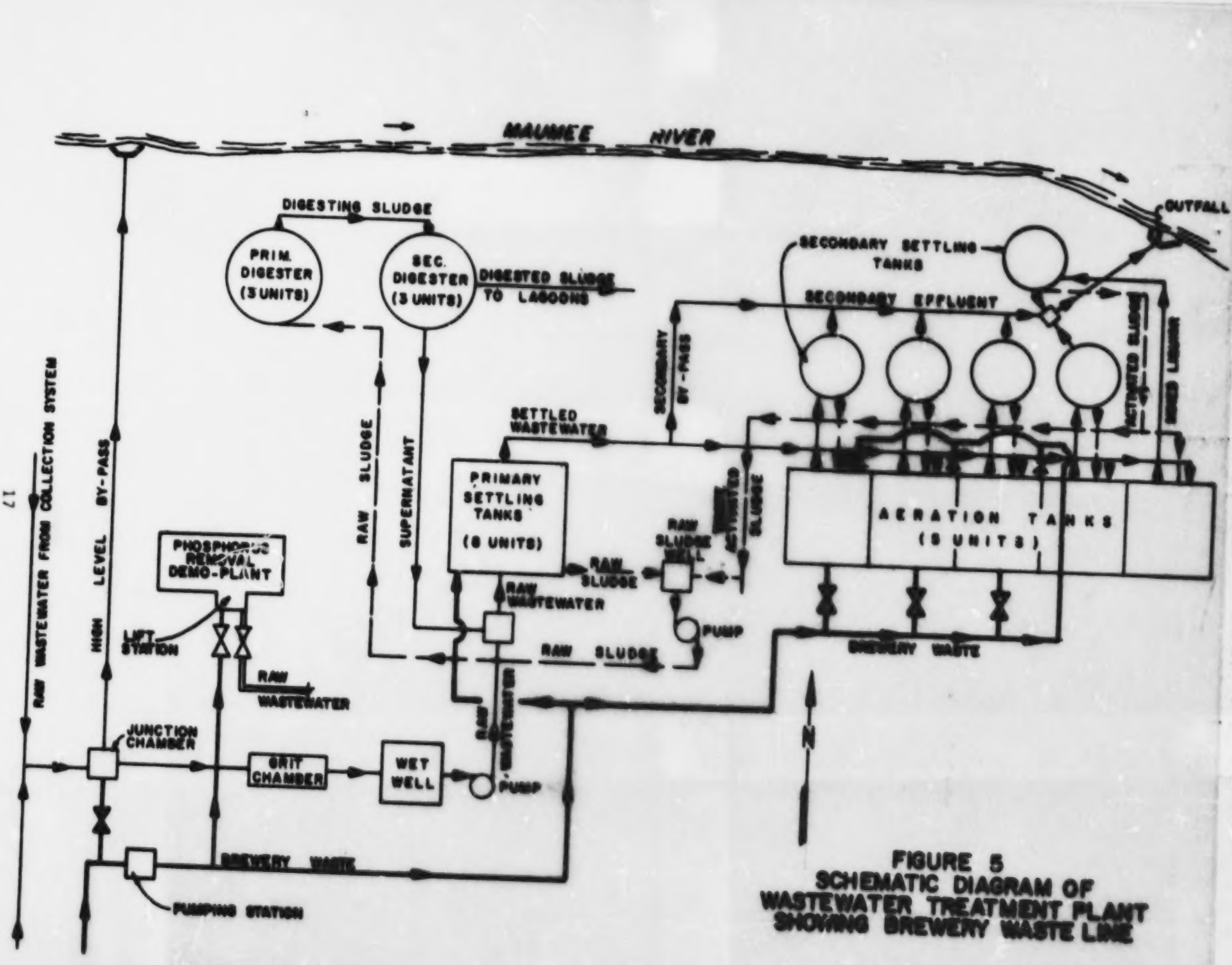


FIGURE 5
SCHEMATIC DIAGRAM OF
WASTEWATER TREATMENT PLANT
SHOWING BREWERY WASTE LINE

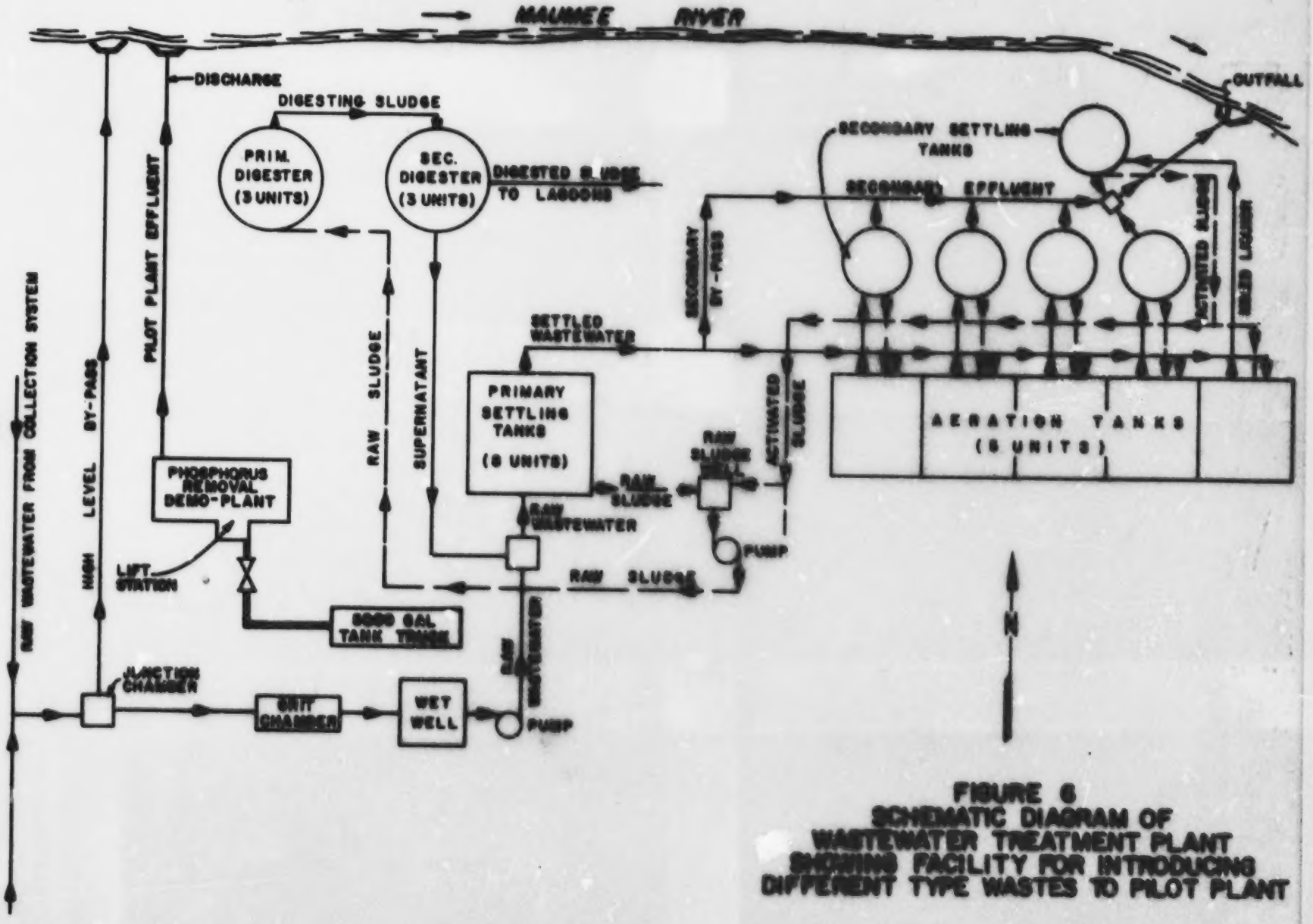
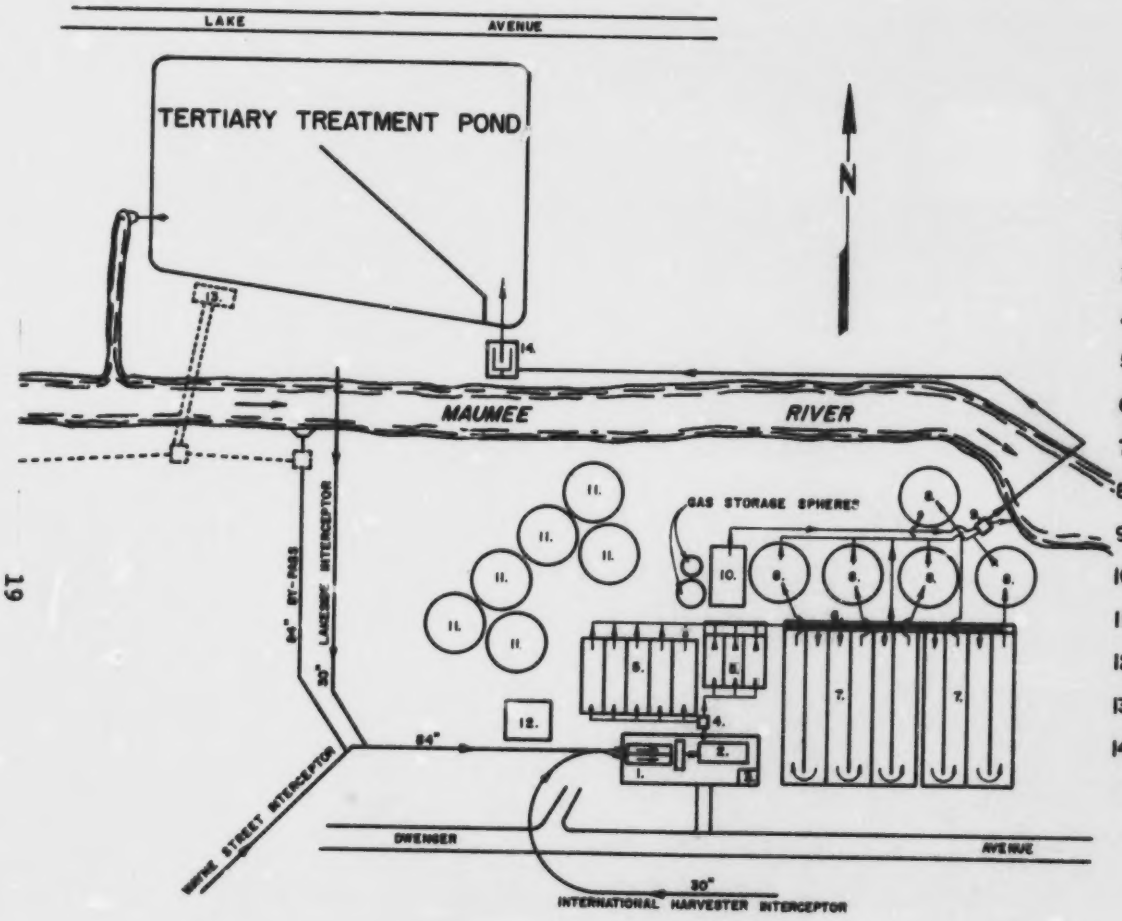


FIGURE 6
SCHEMATIC DIAGRAM OF
WASTEWATER TREATMENT PLANT
SHOWING FACILITY FOR INTRODUCING
DIFFERENT TYPE WASTES TO PILOT PLANT



1. GRIT CHAMBERS
2. BLOWER ROOM & RAW WASTEWATER PUMPS
3. LABORATORY
4. DIVERSION STRUCTURE
5. PRIMARY SETTLING TANKS
6. AERATION BUILDING
7. AERATION TANKS
8. SECONDARY SETTLING TANKS
9. CHLORINE INJECTION CHAMBER
10. CHLORINE BUILDING
11. SLUDGE DIGESTERS
12. PHOSPHORUS REMOVAL DEMONSTRATION PILOT PLANT
13. STORMWATER SCREENING INSTALLATION (FUTURE)
14. CHLORINE CONTACT TANK

FIGURE 7
TERTIARY POND LOCATION

SECTION VI

PHOSPHORUS REMOVAL STUDIES

CITY WASTEWATER TREATMENT PLANT

The City wastewater treatment plant was operated in a manner so that essentially all of the wastewater was given treatment in this conventional activated sludge plant. Extensive data was collected on all phases of the operation. Of great interest was the possible influence of waste lime sludge on the removal of phosphorus from the incoming wastewater.

Table 1 shows that the wastewater flow to the treatment plant was essentially the same for the years 1968 through most of 1971. Table 2 shows the suspended solids in the raw wastewater and in the primary effluent. Of the data presented, January, 1968, was the only month in the reported period when spent lime sludge was added to the wastewater influent to the primary settling tanks. From February, 1968, to February, 1970, no spent lime sludge was processed in the wastewater treatment plant. From February, 1970, through August, 1970, various modes of operation with spent lime sludge were investigated. Starting in September, 1970, spent lime sludge was added to the primary effluent as a regular practice.

In the period 1968 to 1971, for varying reasons, the monthly average mixed liquor suspended solids (MLSS) concentrations varied significantly as shown in Table 3. The variations in mixed liquor volatile suspended solids (MLVSS) are shown in Table 4 where the minimum is 1,360 mg/l and the maximum is 2,940 mg/l.

The total and soluble phosphorus in the raw wastewater and the final effluent are shown in Table 5 as monthly averages for the 1968-1971 period. The amount of lime added was calculated by using the average removal of suspended solids in the primary tanks when no waste lime sludge was being added to the raw wastewater, the suspended solids in the raw wastewater, the wastewater flow, and the difference between the suspended solids found in the primary effluent with spent lime sludge in it and the suspended solids in the primary effluent during the baseline period.

The pounds of phosphorus removed in 1968 and 1969, when no spent lime sludge was being added, are shown as pounds of phosphorus removed per day (monthly averages) in Table 6. The average removal during this period was 533 pounds per day.

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TABLE 1

WASTEWATER FLOW

	1968		1969		1970		1971	
	MGD	pH	MGD	pH	MGD	pH	MGD	pH
Jan.	31.4	8.4	34.9	7.6	28.1	7.6	26.8	7.6
Feb.	35.0	7.9	32.6	7.6	32.8	8.3	40.3	7.6
Mar.	30.1	7.9	25.6	7.6	33.1	7.6	36.0	7.6
Apr.	31.2	7.7	32.0	7.5	42.6	7.5	28.3	7.5
May	32.6	7.6	32.5	7.3	35.7	7.4	30.2	7.5
June	30.1	7.4	34.4	7.2	30.1	7.4	29.6	7.4
July	24.6	7.3	35.5	7.3	30.1	7.3	26.9	7.4
Aug.	24.0	7.4	27.1	7.2	25.8	7.2	27.1	7.4
Sept.	23.6	7.4	27.5	7.2	28.5	7.2	31.6	7.4
Oct.	24.4	7.5	29.5	7.3	28.5	7.3	----	---
Nov.	31.1	7.5	31.2	7.4	31.1	7.4	----	---
Dec.	31.9	7.6	25.5	7.5	31.8	7.5	----	---
Avg.	28.2	7.6	30.7	7.4	31.5	7.5	30.8	7.5

TABLE 2

SUSPENDED SOLIDS

(mg/l)

	1968			1969			1970			1971		
	Raw	Prim. Eff.	% Rem.	Raw	Prim. Eff.	% Rem.	Raw	Prim. Eff.	% Rem.	Raw	Prim. Eff.	% Rem.
Jan.	297	128	56.9	191	130	32.0	168	126	25.0	177	220*	-24.3
Feb.	165	112	32.1	177	106	40.1	302	141	53.3	168	224*	-33.3
Mar.	173	106	38.7	198	102	48.5	178	143	19.7	148	178*	-20.3
Apr.	181	115	36.5	183	114	37.7	155	121	21.9	182	339*	-86.3
May	170	100	41.2	183	137	25.1	141	106	24.8	182	291*	-59.9
June	216	99	54.2	191	143	25.1	173	114	34.1	182	268*	-47.3
July	189	103	45.5	172	106	38.4	152	118	22.4	212	293*	-38.2
Aug.	198	97	51.0	170	89	47.7	180	94	47.8	213	236*	-10.8
Sept.	195	104	46.6	178	89	50.0	179	191*	-6.7	189	228*	-20.6
Oct.	197	156	20.8	181	111	38.7	177	269*	-52.0	---	---	-----
Nov.	182	148	18.7	148	95	35.8	149	197*	-32.2	---	---	-----
Dec.	174	139	20.1	174	104	40.3	180	247*	-37.2	---	---	-----
Avg.	194	117	39.7	179	110	38.5	177	155	12.4	184	256*	-39.1

* Spent lime added to primary effluent

TABLE 3

MIXED LIQUOR SUSPENDED SOLIDS (MLSS)

(mg/1)

	1967	1968	1969	1970	1971
January	2666	3579	2986	2654	4428
February	3050	3334	3475	2931	3928
March	3297	2391	2517	2543	4071
April	3221	2750	3090	3054	3645
May	2653	2561	2573	3045	4982
June	2506	2654	2897	3438	4938
July	2200	2639	2223	3237	5609
August	2994	2505	1723	2944	5273
September	3200	2793	1737	3827	5254
October	2637	2714	2198	5306	4438
November	2593	2524	2277	5757	----
December	3698	2514	2448	6384	----

TABLE 4

MIXED LIQUOR VOLATILE SUSPENDED SOLIDS (MLVSS)

(mg/l)

	1967	1968	1969	1970	1971
January	1410	1860	2000	2100	2520
February	1650	2000	2160	1930	2280
March	1950	1750	1930	1780	2120
April	1940	1930	2160	2020	1820
May	1780	1870	1900	1520	2190
June	1710	1780	1850	1580	2120
July	1500	1740	----	1620	2300
August	----	1680	1360	1500	2480
September	1500	2040	1360	1680	2320
October	----	2040	1720	2280	2000
November	----	1830	1680	2480	----
December	----	1860	1930	2940	----

TABLE 5

PHOSPHORUS - SOLUBLE AND TOTAL

(mg/l as P)

	1968				1969			
	SOLUBLE		TOTAL		SOLUBLE		TOTAL	
	RAW	FINAL	RAW	FINAL	RAW	FINAL	RAW	FINAL
Jan.	2.6	4.1	8.9	5.1	3.2	3.5	8.0	6.1
Feb.	3.4	4.4	9.2	7.6	3.8	5.5	9.1	6.9
Mar.	3.5	4.8	9.1	7.4	6.2	8.3	11.6	9.7
Apr.	4.1	4.8	8.1	6.7	3.4	5.0	8.2	6.1
May	5.0	4.7	7.7	5.6	4.3	6.5	10.2	7.5
June	3.9	4.1	9.6	5.4	4.8	6.2	9.2	7.1
July	5.3	6.2	9.1	7.2	4.2	10.7	8.2	7.4
Aug.	5.5	7.2	10.7	9.0	7.5	7.6	11.3	8.8
Sept.	6.0	7.5	10.0	9.3	6.3	7.8	9.0	9.1
Oct.	6.7	10.1	11.8	13.2	6.5	8.0	12.0	11.3
Nov.	6.1	7.7	12.0	9.7	5.2	6.7	10.9	8.8
Dec.	4.5	5.9	10.9	6.5	6.1	7.1	13.6	11.0
Avg.	4.7	5.9	9.8	7.7	5.1	6.9	10.1	8.3
Percent Increase		25.5			35.3			
Removal			21.4				17.8	

TABLE 5 (Cont.)

PHOSPHORUS - SOLUBLE AND TOTAL

(mg/l as P)

	1970				1971			
	SOLUBLE		TOTAL		SOLUBLE		TOTAL	
	RAW	FINAL	RAW	FINAL	RAW	FINAL	RAW	FINAL
Jan.	5.4	6.5	13.6	13.0	5.1	6.8	12.8	8.3
Feb.	4.0	5.1	11.8	9.2	3.2	4.4	9.6	5.9
Mar.	4.4	5.6	12.9	8.9	3.3	3.6	9.4	6.7
Apr.	3.1	4.7	9.0	6.6	4.3	6.2	11.3	8.5
May	3.3	4.9	8.8	6.7	4.7	6.2	11.6	8.3
June	5.4	6.6	10.9	8.8	4.6	5.5	10.7	7.3
July	5.5	6.2	10.2	8.5	5.9	5.9	11.0	7.2
Aug.	6.2	6.3	10.3	7.7	6.4	6.0	11.5	7.8
Sept.	5.0	5.9	10.3	7.9	5.9	6.1	11.3	7.3
Oct.	5.8	6.4	11.0	8.0	6.0	5.9	11.9	7.6
Nov.	4.7	5.6	10.6	7.0	---	---	---	---
Dec.	---	---	---	---	---	---	---	---
Avg.	4.4	5.3	9.9	7.7	9.9	5.7	11.1	7.5
Percent Increase		20.4			16.3			
Removal			22.2				32.5	

TABLE 6

PHOSPHORUS REMOVED BY PRIMARY TANK AND ACTIVATED SLUDGE
WITH NO LIME SLUDGE SOLIDS

Month	Pounds P Removed Per Day In 1968		Pounds P Removed Per Day In 1969
January	995		554
February	627		598
March	427		406
April	364		560
May	671		734
June	1,002		604
July	391		237
August	340		565
September	138		23
October	+ 286		172
November	589		546
December	1,170		554
TOTAL	6,714	Excluding Oct. Total	5,553
Average	610		463
Average 1968 & 1969		533 Pounds	

Table 7 shows the calculated quantities of spent lime sludge added and the amounts of phosphorus removed in 1970 and 1971, as averages for the months for which data are available. Figure 8 shows the plotted data and the scattering of points makes it unwise to attempt to establish a definite relationship between spent lime additions and phosphorus removals. It can, however, be concluded that with applications of spent lime sludge of over 20,000 pounds per day to a flow of about 31 MGD, an additional 100 to 700 pounds of phosphorus was removed.

The mixed liquor suspended solids and volatile suspended solids concentrations varied considerably during the approximately four year period that is being considered, two years with no spent lime sludge being used and an approximate two year period when spent lime sludge was accepted at the wastewater treatment plant. In an effort to establish whether the phosphorus removal was a function of variation in mixed liquor volatile suspended solids (MLVSS) or spent lime sludge addition, the pounds of phosphorus per thousand pounds of volatile suspended solids under aeration were computed and are shown in Table 8. It is readily apparent that the phosphorus removed per thousand pounds of MLVSS was higher during the period when the spent lime sludge was being added. It seems much more reasonable that the spent lime sludge was chemically responsible for the increased phosphorus removal rather than its acting as a stimulant to the biological process. This latter supposition can not be established as a fact with the data that were collected.

PRELIMINARY PILOT PLANT STUDIES

General

Pilot plant studies for phosphorus removal were started in July, 1970, after completion of construction. The pilot plant has been previously described and shown in Figure 2.

The influent raw wastewater received primary sedimentation prior to treatment in the aerators. The pilot plant was designed for a 4-hour detention period in the aerators with an MLSS concentration of 4,000 mg/l. In addition to organic degradation, the aerator operation was intended to achieve phosphate capture.

The nearly four months of operation during the preliminary pilot plant studies were devoted to the development of procedures for identical control of the two units and the determination of operating characteristics of the entire pilot plant. A summary of operational data is presented in Table 9. During much of the July-November, 1970 period, great difficulty was experienced in handling and controlling the return sludge. An indication of this difficulty is partially shown by the sludge volume index figures in Table 9. The operation of the units can also be compared by noting the removals of suspended solids, BOD, and total phosphorus shown in Table 10.

TABLE 7

LIME SLUDGE SOLIDS ADDED AND
TOTAL PHOSPHORUS REMOVED
BY PRIMARY AND SECONDARY TREATMENT

1970 Month	Pounds Lime Sludge Solids/Day	Pounds P Removed Per Day	1971 Month	Pounds Lime Sludge Solids/Day	Pounds P Removed Per Day
Feb.	5,610	608	Jan.	25,100	1,010
Mar.	-----	1,095	Feb.	41,000	1,240
Apr.	9,650	662	Mar.	26,400	810
May	9,250	746	Apr.	53,900	660
June	5,950	625	May	45,600	832
July	2,010	426	June	38,600	836
Aug.	6,280	653	July	36,700	851
Sept.	19,500	570	Aug.	24,000	836
Oct.	38,200	714	Sept.	28,200	1,056
Nov.	26,400	934			
Dec.	36,300	---			

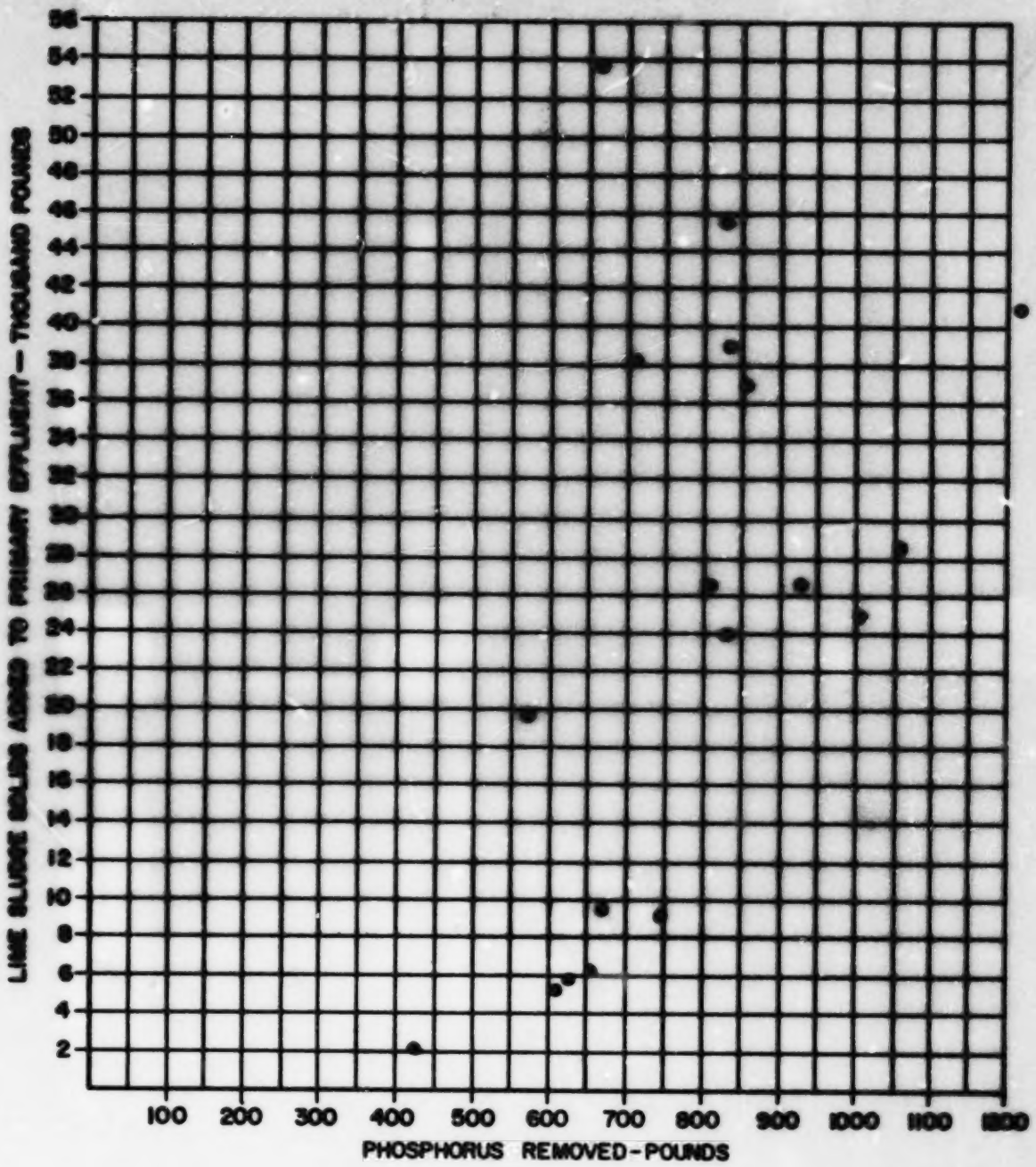

FIGURE 8
PHOSPHORUS REMOVED VS. SPENT
LIME SLUDGE SOLIDS ADDED
IN PRIMARY AND SECONDARY
TREATMENT

TABLE 8

POUNDS OF PHOSPHORUS REMOVED PER DAY PER THOUSAND POUNDS OF MLVSS UNDER AERATION

Month	1968	1969	1970	1971
January	6.1	3.2	---	4.6
February	3.6	3.2	3.6	6.2
March	2.8	2.4	7.0	4.4
April	2.2	3.0	3.7	4.1
May	4.1	4.4	5.6	4.3
June	6.4	3.7	4.5	4.5
July	2.6	---	3.0	4.2
August	2.3	4.7	5.0	3.8
September	0.8	0.2	3.9	5.2
October	---	1.1	3.6	---
November	3.7	3.7	4.3	---
December	7.2	3.2	---	---
Average	3.80	2.98	4.42	4.59
Two Year Average	3.39		4.50	

TABLE 9

PRELIMINARY PILOT PLANT OPERATION

1970 Month	Suspended Solids (mg/1) Raw	Prim. Eff.	Final #1	Final #2	BOD (mg/1) Raw	Prim. Eff.	Final #1	Final #2	Mixed Liquor Suspended Solids (mg/1) #1 Unit	#2 Unit
July	171	153	35	31	130	120	28	25	3222	3677
Aug.	178	143	30	48	154	139	28	33	1842	2251
Sept.	179	159	28	50	145	147	16	28	2265	2338
Oct.	177	151	46	42	158	156	32	41	2950	2400
Nov.	167	145	52	59	150	164	38	46	2710	2240

1970 Month	Sludge Volume Index #1 Unit	#2 Unit	Return Sludge Solids (%) #1 Unit	#2 Unit	Dissolved Oxygen (mg/1) #1 Unit	#2 Unit	Total Nitrogen (mg/1) Raw	Prim. Eff.	#1 Unit	#2 Unit
July	70	79	1.31	1.38	4.5	4.9	21.4	22.2	.2	10.9
Aug.	277	311	0.96	0.98	5.0	5.0	23.8	24.8	16.5	15.7
Sept.	356	161	0.86	1.16	4.5	4.3	24.8	25.3	14.8	17.6
Oct.	245	124	1.22	1.25	4.3	3.9	27.6	28.2	14.9	21.0
Nov.	145	105	1.21	1.07	5.2	5.9	22.0	26.4	20.0	19.5

1970 Month	Soluble Phosphorus (mg/1 as P) Raw	Prim. Eff.	#1 Unit	#2 Unit	Total Phosphorus (mg/1 as P) Raw	Prim. Eff.	#1 Unit	#2 Unit
July	4.1	4.3	5.2	5.4	8.1	8.7	9.5	7.5
Aug.	6.9	6.6	6.1	5.8	10.3	11.3	8.7	8.5
Sept.	5.0	5.0	4.6	4.8	10.3	10.7	7.1	8.0
Oct.	5.7	5.7	5.3	4.9	10.8	11.4	8.8	7.6
Nov.	4.9	4.7	4.0	3.5	10.1	8.8	6.6	6.4

TABLE 10

PILOT PLANT REMOVALS

1970	Removals (%)								
	Suspended Solids			BOD			Total Phosphorus		
Month	Prim.	#1*	#2*	Prim.	#1*	#2*	Prim.	#1*	#2*
July	10.5	77.0	79.7	7.7	76.5	79.1	--	-	13.8
Aug.	19.7	79.0	66.4	9.7	79.8	76.3	--	23.0	24.8
Sept.	11.2	82.5	68.6	---	89.1	81.0	--	33.6	25.2
Oct.	14.7	69.5	72.2	1.3	79.4	73.6	--	22.8	33.3
Nov.	13.2	64.1	59.2	---	76.9	72.0	12.9	25.0	27.3
Avg.								25.8	24.9

* Secondary Only

Elutriation of Phosphorus in the Preliminary Studies

During the preliminary studies in September, October, and November, 1970, elutriation of the phosphorus was attempted in the manner indicated in the schematic flow diagram, Figure 9. There were numerous problems encountered in the operation of the equipment and the processes. The data that was collected are summarized in Table 11 and Table 12.

Results of Preliminary Studies

The pilot plant did not produce the high phosphorus removal it was designed to achieve. This plant was designed as a phosphorus separation and concentration process. The biomass in the aerator was expected to serve a dual purpose of capturing the phosphorus in the wastewater and assimilating organic carbon to reduce the BOD of the wastewater. It was believed that the successful phosphorus removal depended upon:

(1) Transfer of the phosphorus to the biomass,

(2) Keeping it there while the organisms separate from the effluent in the final clarifier, and

(3) Rapid settling of the activated sludge mixed liquor.

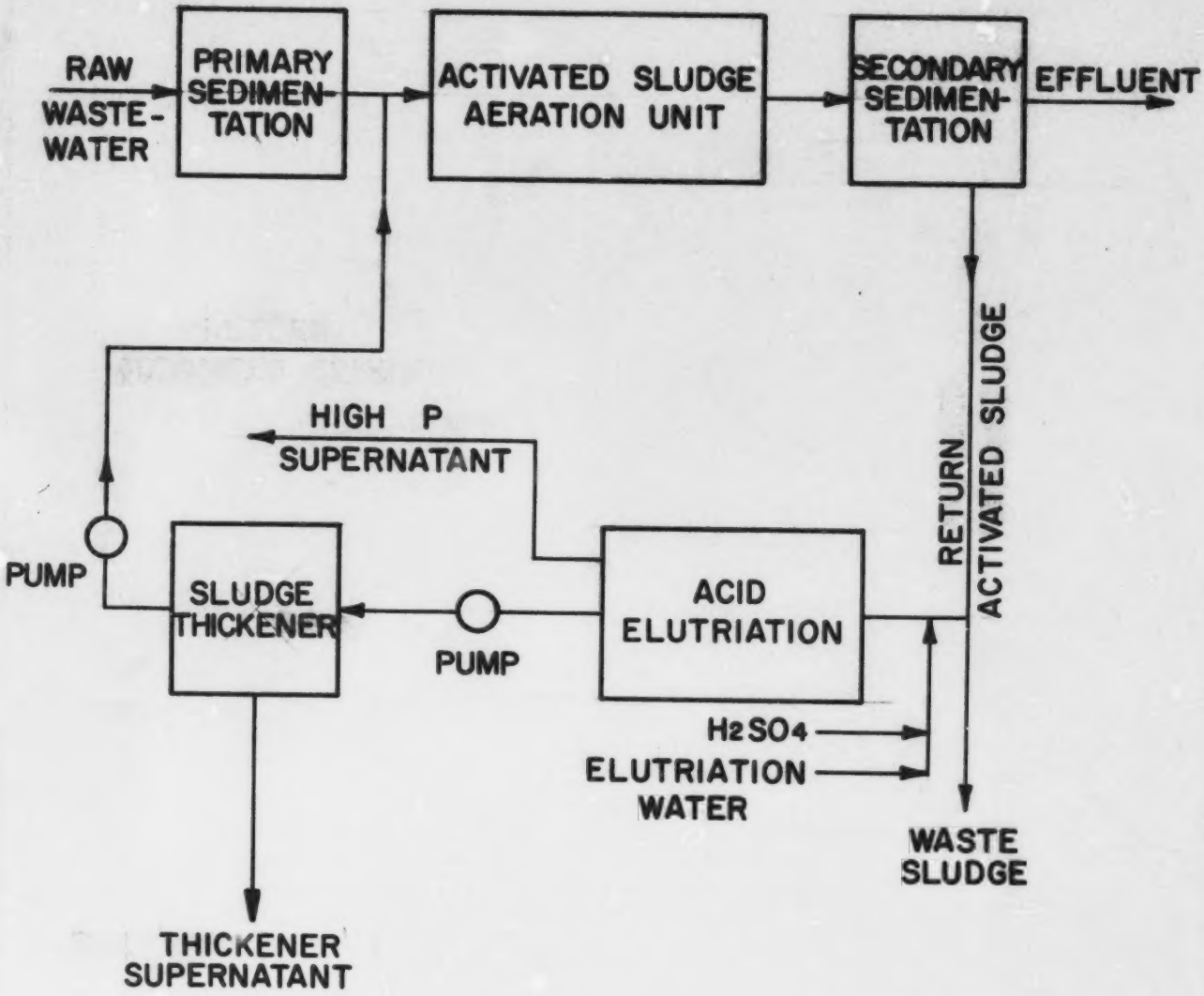

FIGURE 9
PILOT PLANT
SCHEMATIC FLOW DIAGRAM

TABLE 11

CHARACTERISTICS OF ELUTRIATED SLUDGE AND SUPERNATANT

1970	Elutriated Sludge						Supernatant					
Month	Suspended Solids (%)		Volatile %		pH		Suspended Solids (mg/1)		Volatile %		pH	
	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2
Sept.	0.89	1.14	67	74	6.69	5.11	711	78	70	70	7.06	4.79
Oct.	1.22	1.40	71	77	6.65	5.15	31	151	59	77	7.17	5.29
Nov.	----	1.01	--	82	----	5.80	--	214	--	78	----	5.99

TABLE 12

PRELIMINARY PILOT PLANT PHOSPHORUS DATA - 1970

1970	Soluble Phosphorus Supernatant (mg/1)		Total Phosphorus (mg/1)						Turbidity Final Effluent	
			Return Sludge		Elutriated Sludge		Supernatant			
Month	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2
Sept.	4.4	8.4	145	145	134	125	11.5	12.6	14	29
Oct.	3.0	7.4	216	181	214	144	3.8	10.7	17	19
Nov.	---	3.7	189	133	---	99	---	8.3	17	27

It is readily seen that there are several opportunities for complications in the adequate extraction and separation of the phosphorus.

Pilot Plant Modifications

During the preliminary operation period, it was found necessary to make numerous changes in the equipment and operation that included:

1. Sludge Piping - The majority of the existing PVC sludge lines were replaced with flexible hose. This resulted in a reduction of pumping head loss and facilitated cleaning after a blockage.

2. Sludge Withdrawal - The piping on the bottom of each final clarifier was modified to minimize blockage and to facilitate cleaning.

3. Elutriation With Effluent - A small pump was installed in the final stilling box and hose was provided to allow elutriation with final effluent.

4. Acid Mixing - Provision was made to mix the sulfuric acid with the elutriation water prior to mixing with the sludge.

5. Sludge Separation - The original sludge separation system was completely modified to improve performance. The sludge from the elutriation tank was piped directly to the hopper of the existing thickener. Two pumps operating in parallel and a sump pump to discharge the excess sludge from the hopper to the new separation tank were provided. The tank which had originally been provided as a sludge holding tank was modified by the addition of an influent baffle, center baffle, and an effluent weir to act as a sludge separation tank.

6. Aeration - A baffle was installed in the aeration tank of the number two aerator to obtain plug flow.

7. Sludge Collector - A large amount of excess structural material which was not required and tended to retain sludge was removed.

8. Shelter - An air supported structure was purchased and set up to maintain the air temperature above freezing when possible and to prevent wind forces from disturbing the settling units.

THREE-MONTH PILOT PLANT STUDY

General

The preliminary studies with the Fort Wayne pilot plant indicated that a high degree of phosphate removal was not achieved by the activated sludge process. This process of phosphate removal which has worked at some treatment plants has failed to work at others. After completion of some of the pilot plant tests, modifications were instituted. The early operation of the facilities showed a great deal of difficulty in maintaining stable operating conditions with consistently high BOD removals.

Three test runs were made during January, February, and March, 1971. Run No. 1 was terminated after a short period due to extreme losses of mixed liquor solids from the system. Run No. 2 was begun after additional pilot plant modifications were made but it had to be halted for equipment repair. Run No. 3 lasted for one month and it was terminated when little phosphorus removal was achieved. These test runs are described in the following paragraphs:

Run No. 1

Run No. 1 was begun on January 12, 1971. No equipment modifications had been made at this time other than the erection of the air structure housing the pilot plant, and the modification of the acid feeding

system so that the sulfuric acid was diluted before mixing it with the return sludge. The sludge separation equipment, employed for removing the acidified return sludge from the anticipated phosphorus rich supernatant, was the same as had been originally provided and previously used in the preliminary studies.

No activated sludge solids were added to either system from the main plant and the organisms were allowed to multiply normally. On January 25, 1971, a sufficient MLSS level (4,130 mg/1) had been attained that elutriation and acidification were begun.

Figure 10 shows the mixed liquor solids for both the test unit and the control unit. It is clearly shown that the MLSS concentration of the test unit (Unit No. 2) decreased rapidly with elutriation and acidification. The solids were lost in the supernatant of the sludge separator. During the elutriation and acidification, the suspended solids concentration of the separator supernatant averaged 245 mg/1. Run No. 1 was terminated on February 1, 1971, due to the extremely low MLSS in the test aerator.

Figure 11 shows the total phosphorus concentration in the primary effluent feeding the aerators and in the final effluent from the test plant and the control plant (Unit No. 1).

During Run No. 1, City water was used for eleutriation. A large amount of foam was produced in the elutriation tank and it was carried over into the separation unit. Water sprays were used to control the foam.

Run No. 2

After the modifications to the sludge separation and elutriation equipment, Run No. 2 was begun on February 15, 1971. During this run, final effluent was utilized for elutriation and the modified sludge holding tank was used as a sludge separator.

The mixed liquor solids used in Run No. 2 were the same as those developed during Run No. 1. During the plant modification period, the sludge was retained in various available tanks with regular feeding.

Prior to the start of acidification, sludge separation had been achieved with little difficulty. The lowering of the pH impaired the settling qualities so greatly that large amounts of sludge were lost in the separator supernatant immediately after acidification was begun. At several times during the run, the top of the sludge blanket was observed to be less than six inches from the water surface. Figure 10 shows that the loss of solids from the system resulted in the lowering of MLSS in the aerator in Test Unit No. 2 to nearly zero.

After acidification began, the effluent was observed to be very cloudy. It appeared that the amount of foam produced in the elutriation unit during Run No. 2 was less than that produced during Run No. 1. Only a minimum of water spray was required for foam control.

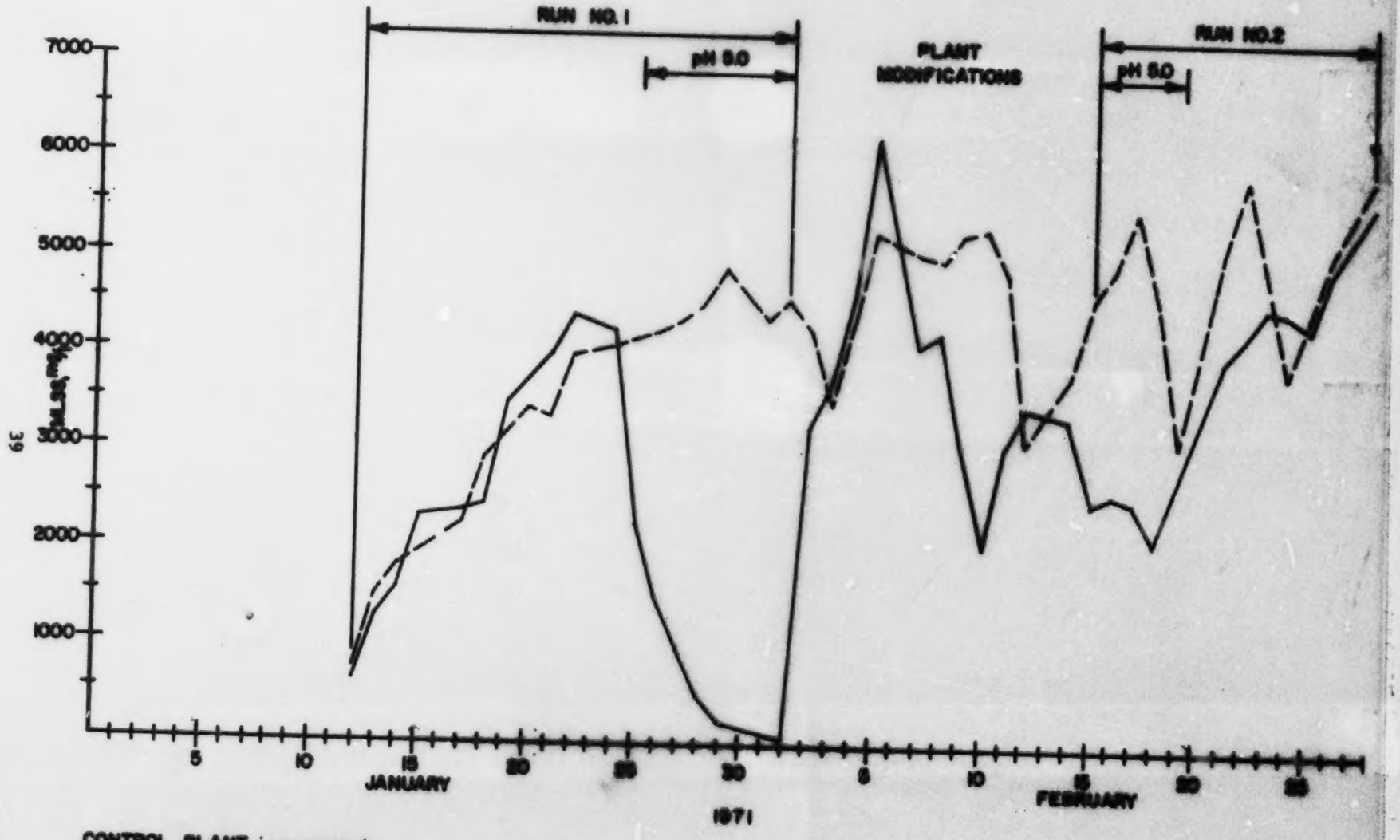

FIGURE 10
MIXED LIQUOR SOLIDS

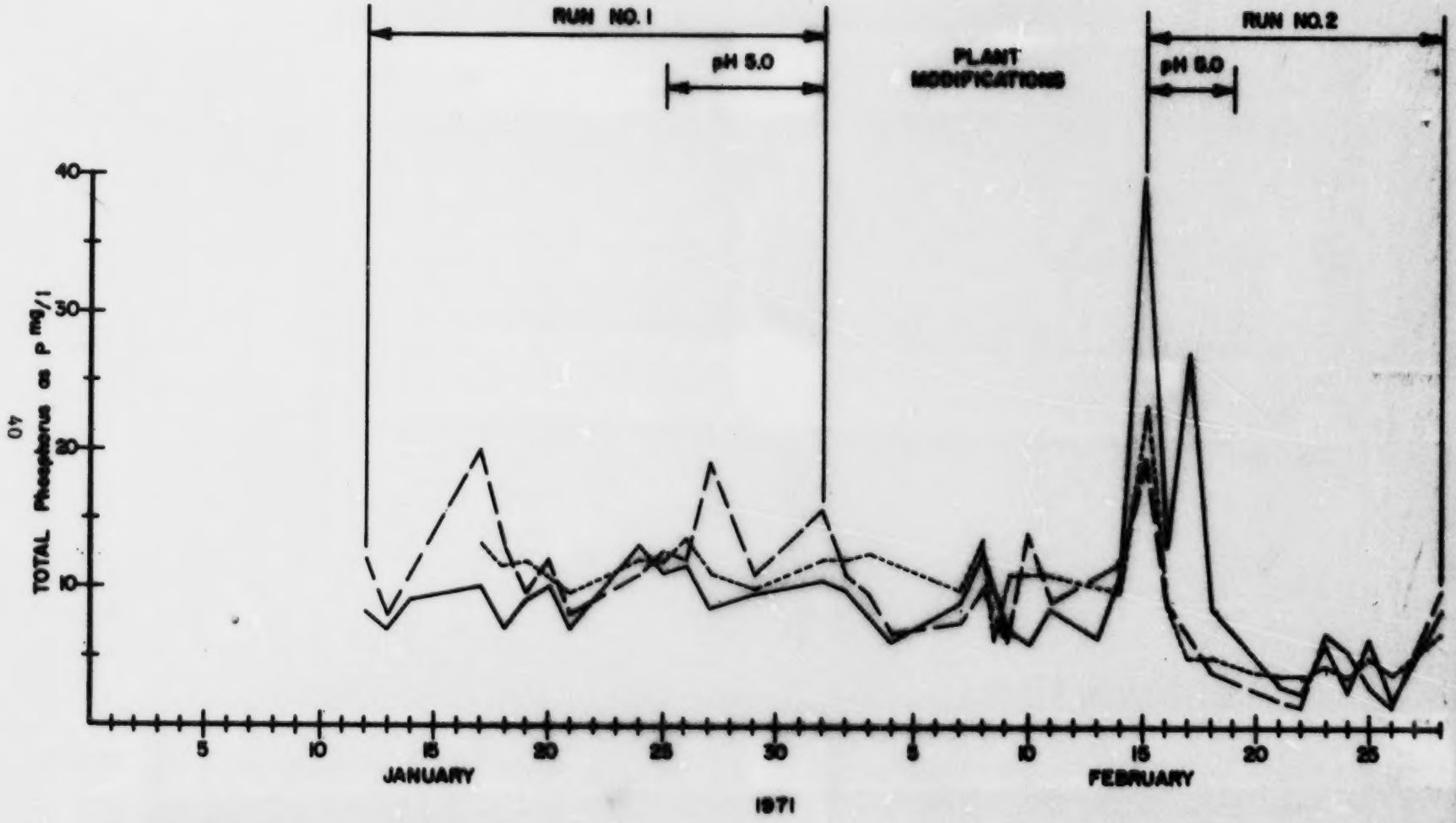

FIGURE 11
TOTAL PHOSPHORUS - PRIMARY EFFLUENT AND FINAL EFFLUENT

Acid feeding was terminated on February 19, 1971, for maintenance of the acid feeding pump.

Run No. 3

Run No. 3 began on March 1, 1971, and continued during the entire month of March. In an effort to minimize sludge losses in the supernatant of the sludge separator, the elutriation pH was lowered slowly to allow for organism adjustment and acclimation. The pH was lowered stepwise to 6.0, 5.0, and finally to 4.5. This action was not wholly successful as the suspended solids concentration in the supernatant was 232 mg/l for the entire run. However, it was possible to hold the MLSS concentration in the test plant aerator to an average of 3,840 mg/l for the entire month.

The variations in mixed liquor solids during the month of March are shown in Figure 12. The phosphorus concentration in the wastewater fed to the aerators and in the effluents from each unit are shown in Figure 13.

Summary of Data

The data collected during the test period beginning on January 12 and ending on March 31, 1971, have been summarized into six periods:

(1) Run No. 1, No acidification

(2) Run No. 1, Acidification

(3) Plant Modifications

(4) Run No. 2, Acidification

(5) Plant Modifications

(6) Run No. 3, Acidification

The information on suspended solids, volatile suspended solids, pH, and BOD in the raw wastewater, primary effluent, and final effluents are summarized in Table 13. The information on MLSS, MLVSS, sludge volume index, and mixed liquor dissolved oxygen is presented in Table 14. Table 15 presents the data for the several periods on total and soluble phosphorus. The summarized data on the elutriation of the return sludge are presented in Table 16. The information on soluble and total phosphorus in the supernatant, return sludge, and elutriated sludge and the turbidities of the two final effluents are summarized in Table 17.

Discussion of Results

Great difficulty was experienced in maintaining an MLSS concentration at the desired value while practicing acidification and elutriation. In addition, difficulty was experienced with bulking of the activated sludge as can be noted in Table 14, but this difficulty was not con-

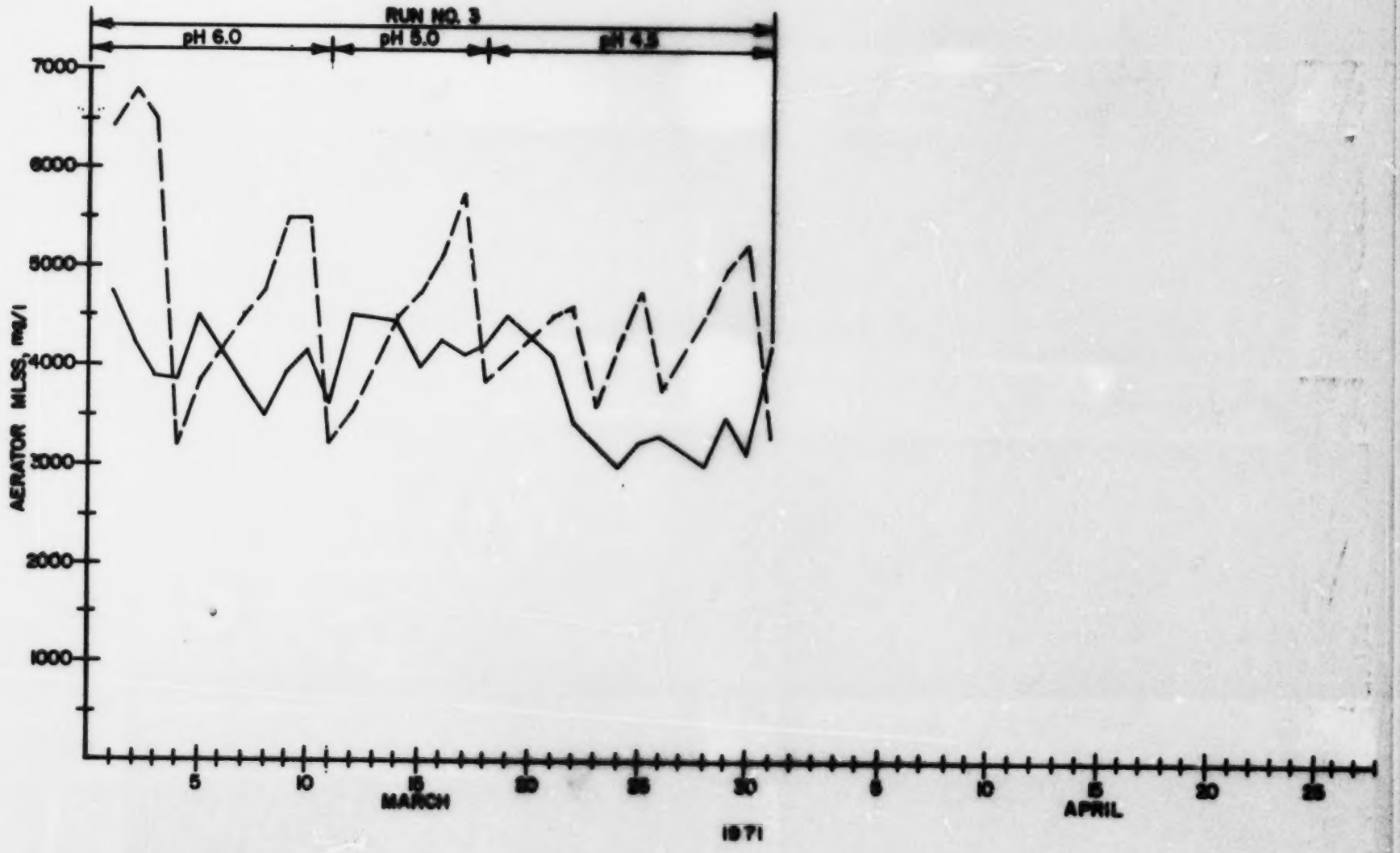

FIGURE 12
MIXED LIQUOR SOLIDS

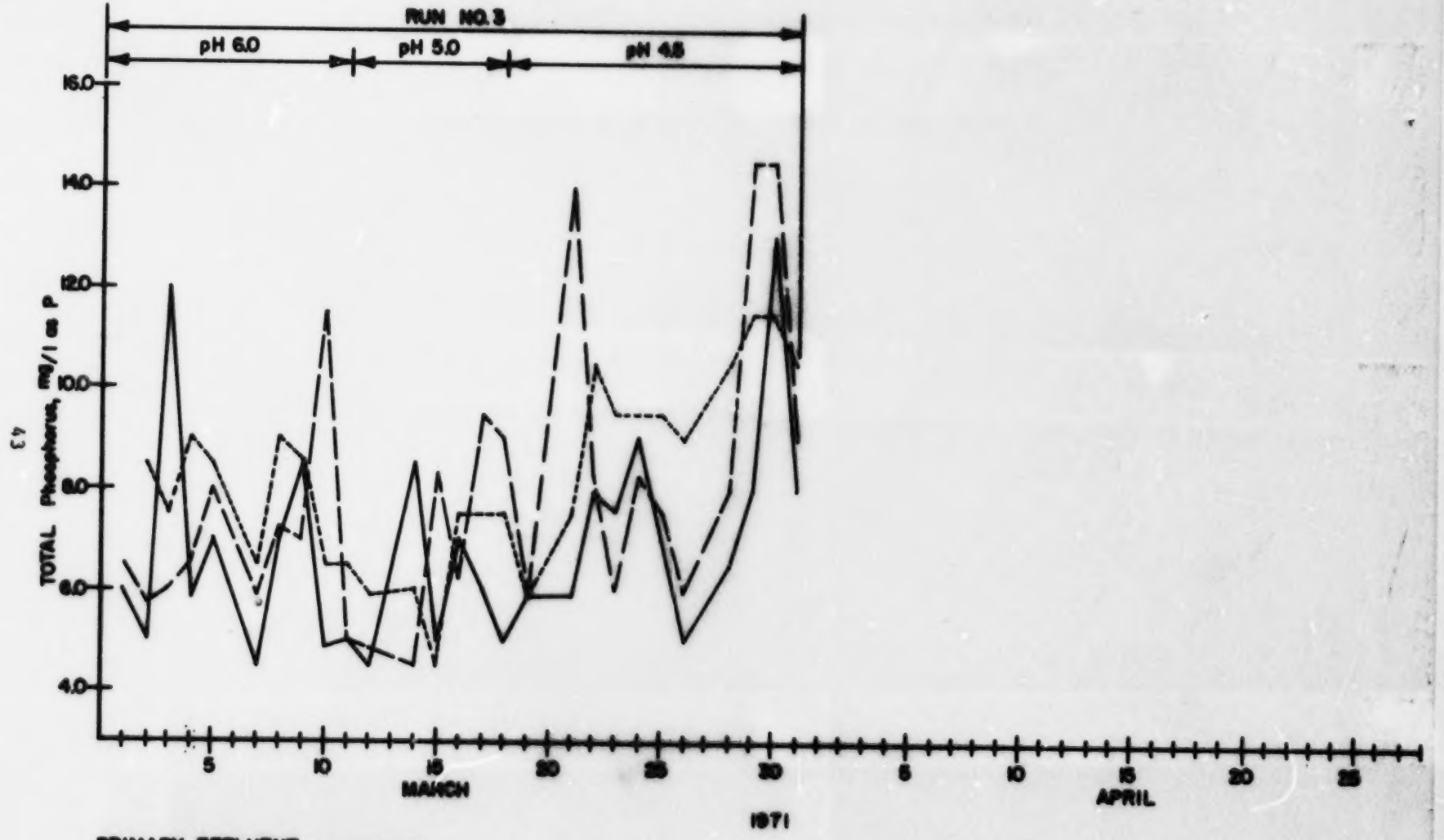

FIGURE 13
TOTAL PHOSPHORUS - PRIMARY EFFLUENT AND FINAL EFFLUENT

TABLE 13

PILOT PLANT DATA - BOD, SUSPENDED SOLIDS, AND pH

Period	Suspended Solids (mg/l)				% Volatile Suspended Solids				pH				BOD (mg/l)			
1971	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2
1/12-1/23	193	167	57	70	75	73	76	77	7.61	7.45	7.47	7.50	193	192	50	49
1/24-2/1	174	119	68	79	79	80	71	79	7.54	7.43	7.37	7.41	213	193	45	112
2/2-2/14	172	166	41	40	70	68	75	74	7.60	7.51	7.41	7.41	174	195	21	24
2/15-2/19	172	150	37	118	59	61	81	69	7.61	7.50	7.30	7.16	130	148	16	97
2/20-2/28	164	161	63	47	45	40	45	53	7.65	7.58	7.42	7.42	91	102	8	10
3/1-3/31	148	131	33	45	72	69	72	70	7.60	7.53	7.38	7.33	153	161	27	35

TABLE 14

PILOT PLANT DATA -

MIXED LIQUOR CHARACTERISTICS

Period	Mixed Liquor Suspended Solids (mg/l)		Volatile Suspended Solids %		Sludge Volume Index		Mixed Liquor Dissolved Oxygen (mg/l)		Remarks
1971	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	
1/12-1/23	2560	2618	76	73	67	82	5.8	7.2	Run No. 1 - No Acidification
1/24-2/1	4327	1068	77	83	145	118	4.7	7.9	Run No. 1 Acidification
2/2-2/14	4530	3825	69	71	83	88	6.9	8.0	Plant Modifications
2/15-2/19	4445	2664	70	75	61	65	7.2	8.4	Run No. 2 Acidification
2/20-2/28	5352	4728	41	51	32	43	8.9	10.1	Plant Modifications
3/1-3/31	4677	3842	63	67	66	51	4.2	4.0	Run No. 3

TABLE 15

PILOT PLANT DATA -

PHOSPHORUS IN MAIN FLOW STREAM

Period	Soluble Phosphorus (mg/l as P)				Total Phosphorus (mg/l as P)				Total Phosphorus Removal (%)			
		Prim.	Final	Final		Prim.	Final	Final	Overall		Aeration	
1971	Raw	Eff.	#1	#2	Raw	Eff.	#1	#2	#1	#2	#1	#2
1/12-1/23	4.9	5.0	4.5	4.5	11.6	10.9	10.5	9.1	9.5	21.6	3.7	16.5
1/24-2/1	5.3	5.0	6.1	4.9	13.0	11.4	11.4	10.4	12.3	20.0	0	8.8
2/2-2/14	4.4	4.0	4.5	4.0	12.1	9.9	9.7	8.1	19.8	33.1	2.0	16.2
2/15-2/19	3.0	2.9	3.3	4.2	9.1	10.3	9.6	21.9	---	---	6.8	---
2/20-2/28	1.6	1.8	1.6	1.4	4.8	4.5	4.0	4.8	16.7	---	11.1	---
3/1-3/31	3.3	3.2	3.5	3.1	9.4	8.3	7.9	6.9	16.3	26.6	4.8	16.9

TABLE 16

PILOT PLANT DATA - RETURN SLUDGE, ELUTRIATED SLUDGE, SUPERNATANT

1971	Return Sludge						Elutriated Sludge						Supernatant					
Period	Suspended Solids (%)		Volatile Suspended Solids (%)		pH		Suspended Solids (%)		Volatile Suspended Solids (%)		pH		Suspended Solids (%)		Volatile Suspended Solids (%)		pH	
	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2
1/12-1/23	1.00	.91	76	76	7.13	7.13	--	--	--	--	--	--	--	--	--	--	--	--
1/24-2/1	1.47	.68	78	87	7.09	7.08	--	.44	--	89	--	5.41	--	216	--	85	--	5.13
2/2-2/14	1.49	1.80	72	73	7.13	7.04	--	.96	--	72	--	7.00	--	1468	--	71	--	7.40
2/15-2/19	1.45	1.06	72	75	7.05	6.77	--	1.03	--	77	--	5.39	--	631	--	70	--	5.06
2/20-2/28	1.77	2.01	44	49	7.20	7.20	--	1.65	--	51	--	7.01	--	135	--	45	--	7.56
3/1-3/31	1.46	1.50	64	68	7.11	6.96	--	1.45	--	68	--	6.16	--	232	--	70	--	6.38

TABLE 17

ADDITIONAL PILOT PLANT PHOSPHORUS DATA - 1971

1971	Soluble Phosphorus		Total Phosphorus						Turbidity	
	(mg/l as P)		(mg/l as P)						Final Effluent	
	Supernatant		Return Sludge		Elutriated Sludge		Supernatant		JTU	
Period	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2
1/12-1/23	--	--	227	222	--	--	--	--	22	23
1/24-2/1	--	4.3	237	99	--	51	--	7.7	29	44
2/2-2/14	--	5.6	206	236	--	139	--	56.0	13	16
2/15-2/19	--	7.2	200	110	--	108	--	18.6	12	60
2/20-2/28	--	1.4	114	132	--	121	--	4.1	24	22
3/1-3/31	--	4.6	192	164	--	139	--	10.3	16	21

fined to the test unit as can be noted for Period No. 2 when the average sludge volume index for the control unit (No. 1) was 145 vs. 118 for the test unit (No. 2).

The percent volatile solids of the mixed liquor were consistently higher in the test unit than they were in the control except for Period No. 1. It seems reasonable to assume that the acidification dissolved some of the inert solids from the sludge, thus increasing the percent volatile solids.

The dissolved oxygen concentration of the mixed liquor was on the average above 4.0 mg/l in both units. It can, therefore, be assumed that there was ample oxygen in the system at all times.

The phosphorus removals are shown in Table 15 as average values for each period. It appears that there was a removal of total phosphorus in primary treatment. The data indicate removals of phosphorus in the 0 to 16.9 percent range, regardless of whether Unit No. 2 was functioning with acid treatment and elutriation or whether it was not being operated in this fashion. The range of removals in the control system was between 0 and 11.1 percent. Table 15 data show no appreciable removal with the acidification-elutriation process.

The volatile solids of the return sludge of Unit No. 2, the test unit, are equal to or considerably higher than they are for Unit No. 1. The pH of the return sludge was 6.77 for the February 15 to 19 period and 6.96 for the March 1 to 31 period, and for all other periods it was above 7.0. This indicates that the sludge being returned was at a pH not detrimental to the system. The sludge being elutriated was submitted to a pH of 5.39 to 6.16 in the process and no pH adjustment was made before returning the sludge to the aerator. It appears that the buffering capacity of the sludge acted to produce these results.

The solids in the supernatant from the elutriation process were between 216 and 631 mg/l during the acidification periods but it should be noted that they were also very high at times when the pH of the supernatant was above 7.0.

The soluble phosphorus content of the supernatant was between 1.4 and 7.2 mg/l with and without acidification as can be noted by the data presented in Table 17. Acidification may or may not have increased the concentration of soluble phosphorus found in the supernatant.

The data in the total phosphorus content of the return sludge indicate that some phosphorus was removed from the return sludge by the acid treatment. During the acidification periods, the total phosphorus removed from the return sludge was between 15 and 58 percent with the lower value being attained during the long March test period.

The total phosphorus found in the supernatant from the acidification-elutriation process ranged from 717 to 18.6 mg/l during the three periods, but it should be noted that an average value of 56.0 mg/l was found during the February 2 to 14 modification period.

Turbidities were determined on the final effluents during the January 12 to March 31 test period and the range for the control unit effluent was 12 to 29 and the range for the test unit was 16 to 60, thus indicating that the acidification-elutriation process may induce a more turbid effluent.

Unresolved Issues

At the conclusion of the three month pilot plant study, there were still unresolved issues that are defined as areas in the project that require attention and professional study to overcome problems encountered. Three critical issues were defined in this part of the Fort Wayne study. Each is discussed in detail in the following section. The critical areas are:

1. Phosphorus removal
2. Sludge separation
3. Turbid effluent

None of the test runs completed to this time achieved nearly the degree of phosphorus removal expected or required. This phosphorus removal process has been shown to be operable in the laboratory by others, but it is obvious that some departure from the laboratory procedures and conditions were responsible for the poor performance experienced. Some possible variable parameters which may be different than those in the laboratory are:

1. Differences in the characteristics of the wastewater.
2. Differences in the characteristics of the biological population developed.
3. Dissolved oxygen level.
4. Residence time during unit processes.
5. Food to micro-organism ratio.
6. Trace elements present.
7. Plug flow conditions not obtained.

Some current theories indicate that phosphorus removal by the mechanism of luxury uptake does not occur until the soluble BOD level has been reduced below some critical level. When the critical BOD level is passed, phosphorus removal is said to be rapid and nearly complete. In order to achieve phosphorus removal, a low soluble BOD must be preceded by a rapid growth period. This is characteristic only of the plug flow reactor.

In a complete mix reactor, the soluble BOD is the same throughout the reactor and equal to the soluble BOD in the effluent. It has been verified by others that there is no rapid growth period in a complete mix reactor.

If the above is true, then removal of phosphorus can occur best in a plug flow reactor. The aerator in the Fort Wayne pilot plant did not approach plug flow operation. The phosphorus removal in the Fort Wayne wastewater plant (full scale) is certainly plug flow and the phosphorus removal in it is no more impressive than was found in the pilot plant. Of the activated sludge plants that effectively remove phosphorus from wastewater, the only outlet for phosphorus is through the activated sludge wasted. This sludge has been reported to contain up to 7 percent P by weight, which indicates the luxury uptake. The sludge produced in the pilot plant averaged only 1.4 percent P, with a maximum of 1.8 percent and a minimum of 1.1 percent. The elutriation process failed to remove any significant portion of the phosphorus. The average phosphorus percentage in the elutriated sludge was 1.4 percent. Only when the phosphorus content of the sludge exceeds 2 percent can part of the phosphorus be attributed

to luxury uptake. It is evident that luxury uptake was not achieved in Run No. 3. Considerable difficulty was experienced in removing the sludge from the supernatant after acidification and elutriation. The converted sludge separator had a detention time of 3 hours based on a flow of 6.0 gpm. Thus, unless other processes can produce more rapid separation, the proposed process will not be economically feasible due to the large size of separators required.

It is entirely possible that the loss of sludge separation characteristics was due to the acidification. It was noted on several runs that better separation properties were attained by the use of water only.

Possible solutions to the critical issue of sludge separation may be:

1. Chemical additions to increase settling velocity
2. Centrifugation
3. Flotation
4. Addition of spent lime sludge

Possible solutions to increased effluent turbidity as noted in the Fort Wayne pilot studies are:

1. Chemical additions
2. Filtration
3. Tertiary ponds
4. Addition of spent lime sludge
5. Increased efficiency in settling tank operation

SIX-MONTH PILOT PLANT STUDY

General

The previously described three-month pilot plant study exhibited a very low removal of phosphorus. It was decided that pilot plant studies should be carried out incorporating into the procedures for operation some of the indicated guides learned during the three months study. The time between April 1 and October 25, 1971, was divided into new operating periods exclusive of September when no tests were made. These periods of operation have been designated by period numbers from 7 through 15 as shown in Table 18 with accompanying dates and brief titles. A summary of plant operational data for Periods 7 through 15 are presented in Table 19 through 24.

TABLE 18

PERIOD DESIGNATIONS FOR

SIX-MONTH PILOT PLANT STUDY

Period Number	Dates (1971)	Brief Table
7	April 1 to May 16	Standard Activated Sludge
8	May 17 to June 6	Lime and Polyelectrolyte, #2 Unit
9	June 7 to June 25	Lime and Ferric Chloride, #2 Unit
10	July 6 to July 19	Standard Activated Sludge
11	July 20 to July 25	Electro-Flotation, #2 Unit
12	July 26 to July 30	Ferric Chloride, #2 Unit
13	July 31 to August 16	Lime to each Aeration Tank plus Ferric Chloride to #2 Unit
14	August 17 to August 31	Pickling Acid Added, #2 Unit
15	October 3 to October 25	Plug Flow Unit #1 vs. Complete Mix Unit #2

TABLE 19

PILOT PLANT DATA -

SIX-MONTH SUMMARY NO. 1

Period No.	Suspended Solids (mg/l)				% Volatile Suspended Solids				pH				B OD (mg/l)			
	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2
7	187	146	21	31	75	72	76	75	7.50	7.50	7.46	7.46	161	162	15	18
8	194	133	18	18	71	71	77	64	7.39	7.43	7.33	8.03	143	138	11	14
9	192	133	67	26	69	74	70	49	7.44	7.46	7.44	7.63	163	139	44	15
10	228	146	100	24	65	70	72	75	7.34	7.25	7.39	7.50	167	169	58	14
11	203	154	308	26	72	79	81	79	7.14	7.02	7.31	7.34	187	219	157	12
12	252	158	37	92	62	76	79	73	7.84	7.59	7.51	7.31	223	199	33	37
13	230	161	77	41	75	75	70	65	7.45	7.50	7.45	7.41	189	226	48	12
14	218	--	33	36	81	--	64	60	7.30	--	7.49	7.52	174	--	19	11
15	185	128	26	17	77	76	79	71	7.43	7.41	7.60	7.61	188	206	27	4

TABLE 20

PILOT PLANT DATA -

SIX-MONTH SUMMARY NO. 2

Period No.	Mixed Liquor Suspended Solids (mg/l)		% Volatile Suspended Solids		Sludge Volume Index		Mixed Liquor Dissolved Oxygen (mg/l)	
	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2
7	4420	4150	74	73	159	54	4.9	3.9
8	3880	4460	70	57	191	53	3.0	5.5
9	3080	6360	70	48	173	50	3.9	4.8
10	2317	4146	77	70	438	105	3.3	3.9
11	1000	3550	82	74	328	297	4.8	3.0
12	2980	2840	76	71	392	341	2.9	3.8
13	2995	3270	72	65	397	266	3.5	4.0
14	2620	3176	62	68	368	308	4.4	4.3
15	2730	2546	72	78	87	232	4.3	3.0

TABLE 21

PILOT PLANT DATA -

SIX-MONTH SUMMARY NO. 3

Period No.	Soluble Phosphorus (mg/l as P)				Total Phosphorus (mg/l as P)				Total Phosphorus Removal %			
									Overall		Aeration	
	Raw	Prim. Eff.	Final #1	Final #2	Raw	Prim. Eff.	Final #1	Final #2	#1	#2	#1	#2
7	4.0	4.2	4.8	4.9	11.0	10.2	10.3	9.9	6.4	10.0	--	2.9
8	4.3	4.3	5.2	2.4	10.3	9.2	7.8	4.4	24.2	57.3	15.2	52.1
9	4.7	4.4	5.0	1.3	10.3	9.2	10.3	2.3	0	77.7	--	75.0
10	5.6	5.4	6.1	6.3	11.0	9.9	9.0	7.8	18.2	29.1	9.1	21.2
11	6.8	6.5	6.3	6.8	11.1	11.8	14.8	11.3	--	--	--	0
12	6.3	5.8	6.0	1.7	11.4	10.9	9.8	4.0	14.1	64.9	10.1	63.3
13	6.1	6.2	8.9	2.4	11.8	12.2	9.3	3.8	21.2	67.8	23.8	68.8
14	6.4	--	5.5	2.4	11.3	--	8.2	3.0	27.4	68.1	--	--
15	6.2	6.1	6.9	6.7	12.5	11.8	9.4	8.2	24.8	34.4	20.3	30.5

TABLE 22

PILOT PLANT DATA -

SIX-MONTH SUMMARY NO. 4

Period No.	Return Sludge						Elutriated Sludge						Supernatant					
	Suspended Solids (%)		% Volatile Suspended Solids		pH		Suspended Solids (%)		% Volatile Suspended Solids		pH		Suspended Solids (mg/l)		% Volatile Suspended Solids		pH	
	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2
7	1.51	1.09	74	74	7.02	7.09	--	--	--	--	--	--	--	--	--	--	--	--
8	0.92	1.58	71	52	7.07	7.78	--	8.49	--	29	--	4.68	--	166	--	57	--	9.70
9	0.90	1.36	71	50	7.15	7.36	--	2.94	--	31	--	8.95	--	193	--	38	--	9.17
10	0.70	0.99	74	65	6.99	7.03	--	--	--	--	--	--	--	--	--	--	--	--
11	0.51	0.88	77	70	6.96	6.98	--	--	--	--	--	--	--	--	--	--	--	--
12	0.80	0.74	75	69	7.05	7.06	--	--	--	--	--	--	--	--	--	--	--	--
13	0.75	0.53	91	63	7.08	7.15	--	--	--	--	--	--	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15	0.73	0.54	69	69	7.25	7.54	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 23

PILOT PLANT DATA -

SIX-MONTHS SUMMARY NO. 5

Period No.	Soluble Phosphorus (mg/l as P)				Total Phosphorus (mg/l as P)				Turbidity	
	Supernatant		Return Sludge		Elutriated Sludge		Supernatant		Final Effluent JTU	
	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2	Unit #1	Unit #2
7	--	--	243	184	--	--	--	--	7	11
8	--	1.16	166	202	--	1332	--	5.4	8	7
9	--	0.5	133	258	--	624	--	7.8	23	12
10	--	--	110	179	--	--	--	--	30	9
11	--	--	97	153	--	--	--	--	61	10
12	--	--	126	184	--	--	--	--	7	20
13	--	--	121	322	--	--	--	--	25	15
14	--	--	--	--	--	--	--	--	12	14
15	--	--	515	118	--	--	--	--	13	12

TABLE 24

PHOSPHORUS IN RETURN SLUDGE

Period No.	Total Phosphorus as P (%)	
	Unit #1	Unit #2
7	1.6	1.7
8	1.8	1.7
9	1.5	1.9
10	1.6	1.8
11	1.9	1.7
12	1.6	2.5
13	1.6	3.9
14	--	--
15	2.1	2.18

Period No. 7

In period No. 7 (April 1 to May 16), the two pilot plant units were operated as two identical units following conventional practice used in activated sludge plants. The average MLSS concentrations were 4,420 mg/1 in Unit No. 1 and 4,150 mg/1 in Unit No. 2. There was an appreciable difference in the settling characteristics of the sludges as indicated by the average SVI of 159 in Unit No. 1 and 54 in Unit No. 2. Effluent quality from Units 1 and 2 averaged 21 and 31 mg/1 of suspended solids and 15 and 18 mg/1 of BOD, respectively. The dissolved oxygen concentration in the aerators was not markedly different during this test period.

This 47 day test period offered another opportunity to determine the degree of phosphorus removal that can, under normal conditions, be attained with activated sludge at Fort Wayne. The data in Table 21 shows no significant removal of phosphorus was attained. The total phosphorus content of the return sludge was found to be 1.6 percent in Unit No. 1 and 1.7 percent in Unit No. 2.

Turbidity has been a consideration in the evaluation of phosphorus removal processes but in this study they were found to be 7 in Unit No. 1 and 11 in Unit No. 2. These figures are believed to be nearly the same and represent that both effluents can be considered satisfactory from the standpoint of clarity.

Period No. 8

A 21 day study using lime [$Ca(OH)_2$] and polyelectrolyte additions to the activated sludge process was started on May 17, 1971. Unit No. 2 served as the test unit or the one to which the chemicals were added. The polyelectrolyte used had a designation of #676. Between 208 and 312 mg/l of $Ca(OH)_2$ were added to the influent to the aeration tank.

It was possible to maintain a higher MLSS concentration in the test unit than in the control unit. The control unit had an SVI of 191 compared to 53 for the test unit. The volatile solids in the test unit were 57 percent while in the control unit they were 70 percent. These figures show that an appreciable amount of lime was present in the mixed liquor solids. The dissolved oxygen content of the aerator liquor was 3.0 mg/l for the control unit and 5.5 mg/l for the test unit. This was an appreciable difference but not considered to be of great importance in the test results.

The suspended solids in the effluents were, on the average, identical for both units and the BOD's were within 3 mg/l of being the same. There was very little turbidity in either of the effluents.

Phosphorus removal in the test unit was 57.3 percent overall and 52.1 percent across the aerator. The return sludge of No. 1 unit contained 1.8 percent phosphorus while the No. 2 unit sludge contained 1.7 percent, indicating that the electrolyte and lime must have been responsible for the higher phosphorus removal in the test unit. The pounds of P in No. 2 should have been higher than the pounds of P in No. 1 because chemically bound P should have been stored in return and waste activated sludge. However, this does not preclude the percentages measured.

The pH of the final effluent was 8.03 for the test unit and 7.33 for the control unit, an indication of the lime addition to the system.

From this test it is estimated that from 31.5 to 37.5 tons of hydrated lime per day would be required to remove 50+ percent of the phosphorus from 30 MGD of Fort Wayne wastewater.

Soluble phosphorus removed in the test unit during this phase averaged 39.6 percent.

Period No. 9

A 14 day test was made using lime and ferric chloride between June 7 and June 25. The lime dosage was the same 208 to 312 mg/l used in the test conducted in Period No. 8. The quantity of ferric chloride used was 60 mg/l.

In this test period, the MLSS averaged 6,360 mg/l in the test unit and 3,080 mg/l in the control unit, a considerable difference for direct comparison analyses, but the volatile solids were 2,160 mg/l and 3,050 mg/l, respectively. The sludge volume index in the test unit was 50 while the control unit SVI was 173, slightly lower than it was in Period No. 8. The dissolved oxygen of the mixed liquor was 3.9 mg/l in the control unit and 4.8 mg/l in the test unit; the difference is not believed to be great enough to materially modify the environment of the organisms.

The effluent quality of the control unit was not nearly as good as the test unit as judged by the suspended solids, BOD and turbidity and as noted in Table 19 and Table 23.

The volatile solids of the sludge in the test unit were only 48 percent indicating an appreciable amount of inert material from the chemical additions. The volatile solids of the sludge in the control unit were 70 percent, a figure in the range noted in all previous tests where no foreign materials were added to the system.

Phosphorus removal overaged 77.7 percent overall and 75.0 percent across the aerator in the test unit with no indicated removal in the control unit.

The elutriated sludge was more than twice as concentrated as the return sludge. Furthermore it had a smaller percent volatile solids content than did the return sludge and this indicates that there was a larger loss of volatile materials in the supernatant than there was of non-volatile solids. This is substantiated by the 38 percent volatile solids found in the supernatant.

The pH of the supernatant averaged 9.17, indicating that the lime was not all used up in reaction with the ferric chloride.

The results reported in Table 23 show that the concentration of total phosphorus in the elutriated sludge was considerably higher than it was in the return sludge but when the solids concentration is taken into account, the percent phosphorus in the solids was found to be 1.5 and 1.9 percent, respectively.

The supernatant was low in phosphorus averaging 7.8 mg/l total and 0.5 mg/l soluble as P.

The turbidity of the final effluents is shown in Table 23 and the test plant effluent was much clearer than was the control plant effluent.

Period No. 10

In the period July 6 to July 19, 1971, the two pilot plant units were again operated as conventional activated sludge plants. Great difficulty was experienced with the sludge settling in both units. The SVI of #1 unit averaged 438 for the period and in the #2 unit increased from 50 in the prior period to 105. The mixed liquor solids in the #1 unit were 2,317 mg/l, or about half of the 4,146 mg/l in #2 unit. Dissolved oxygen was in the 3+ mg/l range during the period for both units.

Soluble phosphorus was slightly higher in the effluent of both pilot units than in the influent to the units. The data shows a total phosphorus removal of 8.3 percent for #1 unit and 25.8 percent for the #2 unit. This is the range of removals attained in the Fort Wayne wastewater treatment plant.

The volatile solids in the return sludge of #2 unit were 65 percent as compared to 74 percent for the #1 unit. It is probable that the sludge in the #2 unit still retained some of the chemical additives from Period No. 9.

The very poor settling mixed liquor in #1 unit undoubtedly contributed to the high suspended solids, BOD, and turbidity in the effluent from that unit.

Period No. 11

In the period from July 20 to July 25, electroflotation was evaluated for the purpose of minimizing the tank volume required in the separation of sludge solids after elutriation. The unit obtained was supplied by Saint-Gobain Techniques Noservelles - S.G.N., a subsidiary of the Compagnie de Saint - Gobain, France. This equipment provides for the floating of suspended particles by means of gas bubbles electrolytically produced in the liquid itself. The bubbles are expected to be very small and have the particular ability of sticking to those fine insolubles which they entrain and make float to the surface of the treated water.

The electrofloation cell is shown in Figure 14 and consists of two perforated electrodes which occupy the whole section and are fed low voltage rectified current. Above the electrodes an inlet for the liquor to be clarified is provided and below the electrodes an outlet for the clarified water is provided. At the top of the tank there is a sludge removal system.

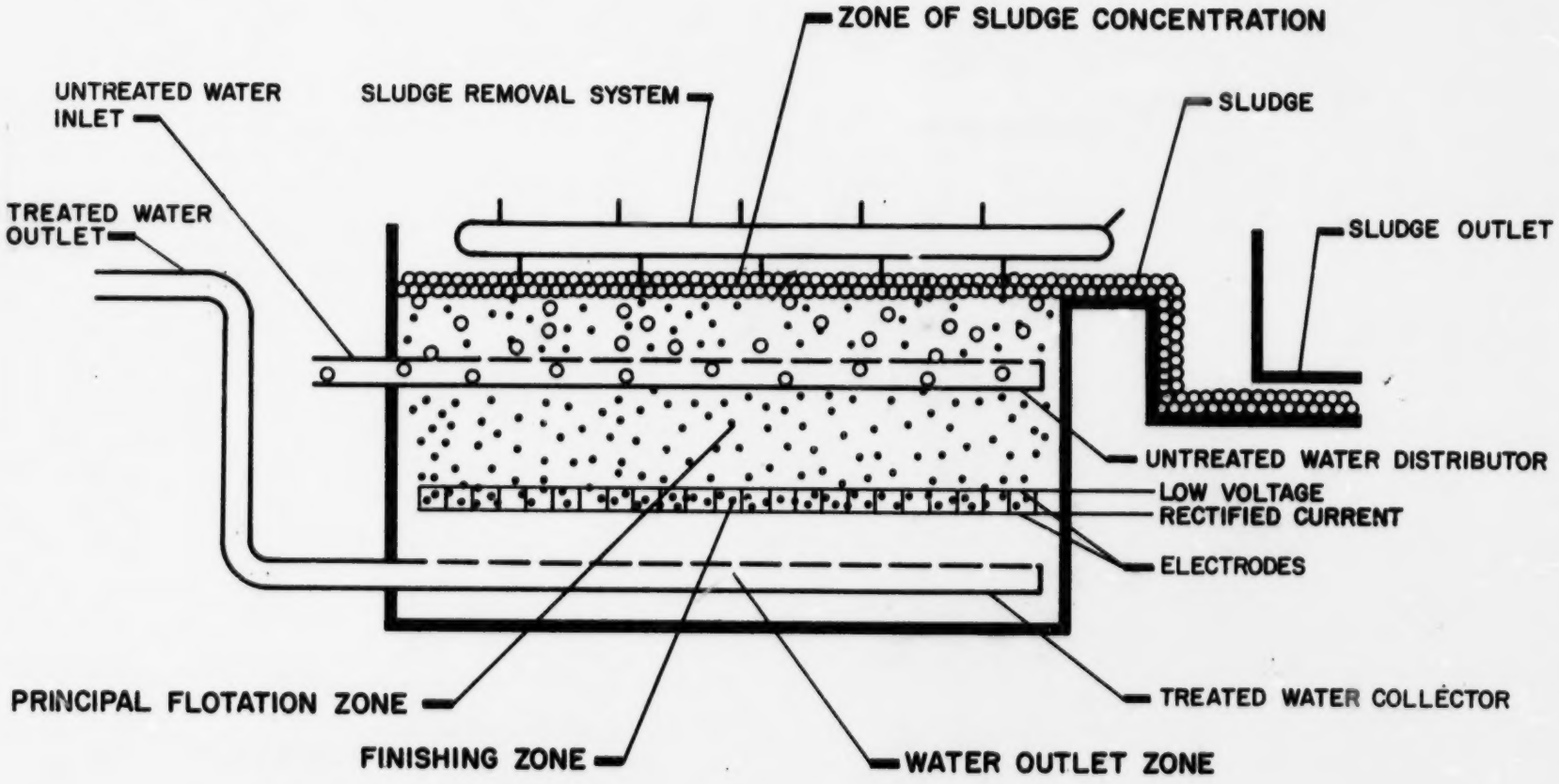

FIGURE 14
ELECTROFLOTATION CELL

The operating system is divided into four zones from top to bottom. The zones are designated as:

1. Zone of sludge concentration
2. Principal flotation zone
3. Finishing zone
4. Treated water outlet zone

In Zone #2 there is turbulence resulting from the electrolytically formed bubbles that become attached to the solids making them buoyant. In Zone #3, the finishing zone, there is a counter flow of bubbles and solids up and liquid down. Zone #4 is hydraulically calm.

An attempt was made to use the electroflotation unit in conjunction with Pilot Plant Unit #2.

The electroflotation unit contained a positive grid and negative grid that were supplied with direct current. Hydrogen gas in fine bubbles was formed. These bubbles attached themselves to sludge particles that were then buoyed to the top of the electroflotation unit where they were supposed to be skimmed from the surface of the liquid.

The electroflotation unit could not be operated as intended because of inherent characteristics that could not be overcome and after two runs of five days each of data collections, the test was discontinued.

The suspended solids and BOD of the raw wastewater fed to the test and the control units were quite high and the mixed liquor solids in aerator #1 were, on an average, only 1,000 mg/l, an indication of a loss of solids from the system. The sludge volume indices for each unit were high indicating a very difficult sludge to handle in sedimentation. The volatile solids of the sludge were very high. The dissolved oxygen concentration was in an acceptable range for both units. The high suspended solids in the effluent from the No. 1 unit, 308 mg/l, show that the sludge was unmanageable.

The results on phosphorus removal shown in Table 21 indicate no removal was attained in either unit. The total phosphorus was found to be 1.9 percent and 1.7 percent, respectively, of the suspended solids in the return sludge and these figures can be compared with the phosphorus in the return sludges in other periods by observing Table 24.

Period No. 12

Period No. 12 extended from July 26 to July 30, a very short time in which to gather operational data. Ferric chloride was added to Unit #2 at the rate of 60 mg/1. The final effluents were high in suspended solids and BOD, particularly in #2 unit. It was possible to maintain the mixed liquor solids at the 2,800 to 2,900 range in both units. SVI's were extremely high and the sludge was difficult to handle in both systems. Dissolved oxygen in the aeration units was maintained at a satisfactory level.

The data on phosphorus removals are shown in Table 21. Phosphorus removal in #2 unit was 64.0 percent for the total system and 63.3 percent across the secondary. Table 24 shows that there was a marked increase in phosphorus in the sludge of #2 unit.

The turbidity of the final effluents were 7 to 20, respectively, for #1 and #2 units. These values indicate an effluent of poor quality as do the suspended solids of 37 and 92 mg/1 for the final effluent of Unit No. 1 and Unit No. 2, respectively.

Period No. 13

Run No. 13 covered a period of seventeen days from July 31 through August 16 when lime was added to each of the aeration tanks with ferric chloride added to Unit #2. The wastewater treated during this period had a suspended solids content of 230 mg/1 and an average BOD of 189 mg/1, both of these factors indicating a rather strong wastewater. The effluents produced were 77 and 41 mg/1 of suspended solids and 48 and 12 mg/1 of BOD, respectively, for #1 and #2 units. MLSS concentrations were 2,995 and 3,290 mg/1. The lime dosage to the aerators was 312 mg/1 $Ca(OH)_2$ in the 10 gpm flow to each aerator. During this period the sludge in both units had an extremely high SVI.

Satisfactory dissolved oxygen in the 3.5 to 4.0 mg/1 range was maintained. The difference in the characteristics in the effluents can be attributed to the 397 SVI for the sludge in Unit No. 1, while the SVI of the sludge in No. 2 unit was 266. The difference in the SVI may have been due to 72 percent volatile solids in the MLSS in the No. 1 unit as against 65 percent in No. 2 unit.

The No. 2 unit that received the lime and ferric chloride removed 67.8 percent total phosphorus while the No. 1 unit that received only lime removed only 21.2 percent of the total phosphorus. The total phosphorus content of the solids in the return sludge of No. 2 unit was 3.9 percent, the highest percentage of phosphorus found in any of the return sludges examined as can be seen in Table 24.

Period No. 14

In the 15 day period, August 17 to August 31, pickling acid was added to the #2 unit to determine its potential as a phosphorus precipitant. The pickling liquor was analyzed for Fe^{+++} and the dosage was regulated to give an iron addition of 60 mg/l $FeCl_3$. The effluents produced in Unit #1 and Unit #2 were 33 and 36 mg/l of suspended solids and 14 and 11 mg/l of BOD, and turbidities of 12 and 14, respectively. MLSS concentrations were 2,620 and 3,170 mg/l with volatile fractions, of 62 and 69 percent. SVI's were 368 in No. 1 unit and 308 in No. 2 unit, both indications of poor settling sludges.

Phosphorus removals were 27.4 percent in No. 1 unit and 68.1 percent in No. 2 unit. Verification of the removals with data on the phosphorus content of mixed liquor or return sludge are not available.

Period No. 15

Period No. 15 covered 23 days in length from October 3 through October 25. The objective was to determine the phosphorus removals under similar conditions except for plug flow in Unit No. 1 and completely mixed flow in Unit No. 2. The suspended solids and the BOD of the raw wastewater averaged 185 and 188 respectively during the period. MLSS concentrations were 2,730 mg/l in No. 1 unit and 2,546 mg/l in No. 2 unit. The volatile solids were in the 72 to 78 percent range. SVI's were 87 in No. 1 unit and 232 in No. 2 unit.

The total phosphorus removal in the two units was similar but not identical. The data show that the removal was about ten percentage points higher in the No. 2 unit than it was in the No. 1 unit. The removals obtained were in the approximate range of those reported for the city plant and for the control units for other periods of operations. The phosphorus content of the return sludge was higher than for other control test periods.

LABORATORY JAR TEST STUDIES

General

In April, May, and June of 1971, nine laboratory jar tests were made to determine the removal of phosphorus that can be obtained by the addition of chemicals to raw wastewater and the primary effluent at Fort Wayne. The chemicals used in the tests were lime (chemical), ferric chloride, and the NALCO Anionic Polymers, No. 675 and No. 676. The combinations of chemicals used in the tests were:

Test No. 1	Lime and NALCO 676
Test No. 2	Lime and NALCO 675

Test No. 3	Lime and NALCO 676
Test No. 4	Lime and Ferric Chloride
Test No. 5	Lime and Ferric Chloride
Test No. 6	Lime, Ferric Chloride, and NALCO 676
Test No. 7	Lime and Ferric Chloride
Test No. 8	Lime and Ferric Chloride
Test No. 9	Lime and Ferric Chloride

In each series of containers, 2,000 ml of liquid were dosed with chemicals as will be specifically stated. After a quick mix, the samples were allowed to stand quiesently for 60 minutes. Samples were collected from the top 100 ml of each container after the settling and analyzed for phosphorus content.

Test No. 1

In Test No. 1, 2,000 ml of raw wastewater in each of eleven containers was dosed with an incremental amount of lime and NALCO 676. Two incremental amounts of 40 and 50 mg/l of lime as CaO were used. The 40 mg/l dose was added to each of five containers and 50 mg/l was added to each of six containers. The NALCO 676 dosages added were from 0.05 mg/l to 0.25 mg/l for each of the two lime dosages.

The data for the test are shown in Table 25. The lowest concentration of phosphorus was obtained with a lime dosage of 417 pounds per million gallons of wastewater combined with 1.67 pounds of NALCO 676 per million gallons of wastewater. A 95 percent removal of phosphorus was attained with a lime dosage of 334 pounds combined with 0.42 pounds of NALCO 676 per million gallons of wastewater. Practically all of the soluble phosphorus (99%) was removed with a lime alone dosage of 417 pounds per million gallons.

Test No. 2

A jar test with raw wastewater was run using 417 pounds of lime and increments of NALCO 675 and NALCO 676. A decant containing 0.24 mg/l (98% removal) of total phosphorus was obtained with the above lime dose and 1.25 pounds of NALCO 675 per million gallons. All other jars to which NALCO 675 was added provided phosphorus removals of 97 percent.

The test in which 417 pounds of lime and 1.67 pounds of NALCO 676 per million gallons of wastewater were added provided a decant with 0.17 mg/l of total phosphorus. This was a 99 percent phosphorus removal. Detailed data on jar test No. 2 are presented in Table 26.

TABLE 25

PHOSPHORUS REMOVAL JAR TEST NO. 1

2,000 ml Raw Wastewater

Phosphorus: Total 8.5 mg/1, Soluble 3.8 mg/1
(as P)

April 20, 1971

Lime (CaO)		Nalco 676	Total Phosphorus as P			Soluble Phosphorus as P	
				Decant	Removal	Decant	Removal
mg/1	lb/MG	mg/1	lb/MG	mg/1	%	mg/1	%
40	334	0.25	2.08	0.45	95	--	--
40	334	0.20	1.67	0.53	94	--	--
40	334	0.15	1.25	0.50	94	--	--
40	334	0.10	0.84	0.56	93	--	--
40	334	0.05	0.42	0.46	95	--	--
50	417	0.25	2.08	0.24	97	0.01	99
50	417	0.20	1.67	0.12	99	0.01	99
50	417	0.15	1.25	0.17	18	0.01	99
50	417	0.10	0.84	0.24	97	0.015	99
50	417	0.05	0.42	0.23	97	0.01	99
50	417	0	0	0.65	94	0.02	99

TABLE 26

PHOSPHORUS REMOVAL JAR TEST NO. 2

2,000 ml Raw Wastewater

Phosphorus: Total 10.8 mg/l, Soluble 4.2 mg/l
(as P)

April 29, 1971

Lime (CaO)		Nalco 675		Nalco 676		Total Phosphorus as P	
mg/l	lb/MG	mg/l	lb/MG	mg/l	lb/MG	Decant mg/l	% Removal
50	417	0.25	2.08	--	--	0.30	97
50	417	0.20	1.67	--	--	0.28	97
50	417	0.15	1.25	--	--	0.24	98
50	417	0.10	0.84	--	--	0.34	97
50	417	0.05	0.42	--	--	0.32	97
50	417	--	--	0.25	2.08	0.17	99
50	417	--	--	0.20	1.67	0.17	99
50	417	--	--	0.15	1.25	0.18	99
50	417	--	--	0.10	0.84	0.22	98
50	417	--	--	0.05	0.42	0.24	98

Test No. 3

Jar test No. 3 was performed using primary effluent, several dosages of lime, and 4.2 pounds of NALCO 676 per million gallons. The lime dosages resulted in a pH range of 9.5 to 11.4. Table 27 shows that with a dosage of lime of 417 pounds and 4.2 pounds of NALCO 676 per million gallons a removal of only 41 percent of the total phosphorus was attained. The only obvious answer to the 41 percent removal in this test was that the high polymer dosage in some manner interfered with the phosphorus removal and at a dosage of 3,336 pounds of lime with 4.2 pounds of NALCO 676 per million gallons of wastewater a removal of 97 percent of the total phosphorus was possible. Data for these tests are summarized in Table 27.

TABLE 27

PHOSPHORUS REMOVAL JAR TEST NO. 3

2,000 ml Primary Effluent

Total Phosphorus: 7.0 mg/1, pH 8.5
(as P)
May 27, 1971

Lime (CaO)		Nalco 676		pH	Total Phosphorus as P	
mg/1	lb/MG	mg/1	lb/MG		Decant mg/1	% Removal
50	417	0.5	4.2	--	4.10	41
100	834	0.5	4.2	9.5	2.10	70
200	1668	0.5	4.2	10.2	0.76	89
300	2502	0.5	4.2	11.0	0.35	95
400	3336	0.5	4.2	11.4	0.19	97

Test No. 4

Test No. 4 was performed in an effort to determine the effectiveness of lime and ferric chloride in the removal of phosphorus. The data in Table 28 shows that a lime dosage of 1,668 pounds per million gallons of wastewater removed 86 percent of the total phosphorus. When this same lime dosage was used in conjunction with 2,369 pounds of ferric chloride per million gallons of wastewater the total phosphorus removal increased to 98 percent.

On the second part of this test, when 2,502 pounds of lime per million gallons of wastewater alone was used, the total phosphorus removal was 93 percent. The removal increased to 99 percent when 2,369 pounds of ferric chloride was used in conjunction with the same lime dose. It was observed that the addition of the ferric chloride reduced the pH from the 10.80 to 11.35 range to the 8.55 to 9.70 range.

Test No. 5

An effort to determine the effectiveness of ferric chloride in the removal of total phosphorus, a jar test was made using 1,668 pounds of lime per million gallons of wastewater in conjunction with 0, 125, 250, 375, and 500 pounds of ferric chloride.

TABLE 28

PHOSPHORUS REMOVAL JAR TEST NO. 4

Phosphorus: Total 4.75 mg/1, pH 7.9
(as P)

June 2, 1971

Lime		Ferric Chloride		pH	Total Phosphorus as P	
mg/1	lb/MG	mg/1	lb/MG		Decant mg/1	% Removal
200	1668	0	0	10.80	0.67	86
200	1668	284	2369	8.55	0.085	98
250	2085	0	0	11.10	0.45	91
300	2502	0	0	11.85	0.35	93
300	2502	284	2369	9.70	0.06	99

Table 29 shows the detailed data of this test. When no ferric chloride was added, the decant contained 0.99 mg/1 of total phosphorus for an overall removal of 91 percent. When a ferric chloride dose of 250 pounds per million gallons of wastewater was used, phosphorus removal increased to 95 percent with a decant concentration of 0.60 mg/1. However, increasing the ferric chloride dosage to 500 pounds per million gallons did not increase the removal above 95 percent.

Test No. 6

In jar test No. 6, lime, ferric chloride, and NALCO 676 were combined in an effort to determine the concentration of ferric chloride that gave the best removal of total and soluble phosphorus with 1,668 pounds of lime and 4.2 pounds of NALCO 676 per million gallons of wastewater. The data shown in Table 30 indicate a 97 percent removal of soluble phosphorus and a 96 percent removal of total phosphorus with a ferric chloride addition of 500 pounds per million gallons of wastewater. The decant contained a soluble phosphorus concentration of 0.15 mg/1 and a total phosphorus concentration of 0.29 mg/1. However, a ferric chloride dosage of 125 pounds per million gallons produced an almost equally good decant with a total phosphorus concentration of 0.37 mg/1 and a soluble phosphorus concentration of 0.21 mg/1. In this test, the ferric chloride and lime were added at the same time. The pH decreased only from 10.2 to 10.05 as the ferric chloride dose was increased from 0 to 500 pounds per million gallons.

TABLE 29

PHOSPHORUS REMOVAL JAR TEST NO. 5

2,000 ml Primary Effluent

Phosphorus: Total 10.75 mg/1, pH 7.8
(as P)

June 3, 1971

Lime (CaO)		Ferric Chloride		pH	Total Phosphorus as P	
mg/1	lb/MG	mg/1	lb/MG		Decant mg/1	% Removal
200	1668	0	0	10.2	0.99	91
200	1668	15	125	10.2	0.65	94
200	1668	30	250	10.1	0.60	95
200	1668	45	375	10.05	0.56	95
200	1668	60	500	10.0	0.53	95

TABLE 30

PHOSPHORUS REMOVAL JAR TEST NO. 6

2,000 ml Primary Effluent

Phosphorus: Total 6.50 mg/1,
(as P)
Soluble 4.50 mg/1, pH 8.75

June 4, 1971

Lime (CaO)		Ferric Chloride ($FeCl_3$)		Nalco 676		pH	Phosphorus as P			
							Total		Soluble	
mg/1	lb/MG	mg/1	lb/MG	mg/1	lb/MG		Decant mg/1	% Removal	Decant mg/1	% Removal
200	1668	0	0	0.5	4.2	10.2	0.69	89	0.40	91
200	1668	15	125	0.5	4.2	10.25	0.37	94	0.21	95
200	1668	30	250	0.5	4.2	10.2	0.32	95	0.19	96
200	1668	45	375	0.5	4.2	10.12	0.32	95	0.17	96
200	1668	60	500	0.5	4.2	10.05	0.29	96	0.15	97

Lime and ferric chloride added together.

Test No. 7

Jar test No. 7 was conducted in an effort to determine whether the addition of the lime before the addition of the ferric chloride made any difference in the effectiveness of the chemicals in removing phosphorus. The addition of 2,502 pounds of lime alone resulted in a 94 percent removal of total phosphorus and a 93 percent removal of soluble phosphorus. Table 31 is a presentation of the data collected in Test No. 7. The maximum removal was 98 percent for both total and soluble phosphorus with a dosage of 2,502 pounds per million gallons. With the lime alone dosage, a pH of 11.10 was noted. With the addition of ferric chloride at the 500 pound rate, the pH was 10.70.

Test No. 8

Jar test No. 8 was conducted by adding the ferric chloride before the lime. In this test a 44 percent removal of total phosphorus was attained with a lime alone dosage of 2,502 pounds per million gallons of sewage. The maximum removal (95%) was attained with 2,502 pounds of lime and 250 pounds of ferric chloride per million gallons of wastewater. For the same dosages with the lime added before the ferric chloride in Test No. 8, the removal was 97 percent. Table 32 shows that the pH of the lime alone dosage was 11.10. At the 2,502 pound lime and 500 pound ferric chloride dosage, the pH was found to be 10.75 as compared to 10.70 when the lime was added before the ferric chloride.

Test No. 9

Jar test No. 9 was conducted to further study the effect of the sequence of addition of the lime and ferric chloride. The data collected in this work are presented in Table 33. In this test, the total phosphorus removed with lime alone was 91 percent. Phosphorus removal attained with addition of ferric chloride before the lime was less efficient than with lime alone. When the lime was added before the ferric chloride, increased phosphorus removal was noted.

Summary of Jar Tests

The annual report of the Indiana Stream Pollution Control Board dated June 30, 1971, states that: "Nutrient removal will be required as necessary to protect downstream water quality. Municipalities with a population over 2,000 in the Lake Erie and Lake Michigan basins are to provide at least 80 percent reduction of total phosphorus on or before the end of 1972."

Table 34 shows the data collected in the nine jar tests, assembled in sequence according to the percent removal attained. Table 35 shows the number of chemical combinations that were responsible for some percent removal of total phosphorus.

TABLE 31

PHOSPHORUS REMOVAL JAR TEST NO. 7

2,000 ml Primary Effluent

Phosphorus: Total 5.75 mg/l (as P)
Soluble 3.2 mg/l, pH 8.1

June 7, 1971

Lime (CaO)		Ferric Chloride		pH	Phosphorus as P			
					Total		Soluble	
mg/l	lb/MG	mg/l	lb/MG		Decant mg/l	% Removal	Decant mg/l	% Removal
300	2502	0	0	11.10	0.34	94	0.23	93
300	2502	15	125	10.95	0.165	97	0.26	92
300	2502	30	250	10.95	0.15	97	0.10	97
300	2502	45	375	10.80	0.14	97	0.19	94
300	2502	60	500	10.70	0.12	98	0.08	98

Lime added first, then ferric chloride.

TABLE 32

PHOSPHORUS REMOVAL JAR TEST NO. 8

2,000 ml Primary Effluent

Phosphorus: Total 7.0 mg/l, pH 8.0 (as P)

June 8, 1971

Lime (CaO)		Ferric Chloride		pH	Total Phosphoras as P	
mg/l	lb/MG	mg/l	lb/MG		Decant mg/l	% Removal
300	2502	0	0	11.10	0.43	94
300	2502	15	125	11.10	0.43	94
300	2502	30	250	11.05	0.35	95
300	2502	45	375	10.95	0.37	95
300	2502	60	500	10.75	0.47	93

Ferric chloride added first, then lime.

TABLE 33

PHOSPHORUS REMOVAL JAR TEST NO. 9

2,000 ml Primary Effluent

Total Phosphorus: 5.75 mg/l, pH 7.8
(as P)
June 10, 1971

Lime (CaO)		Ferric Chloride		pH	Total Phosphorus as P		Remarks
mg/l	lb/MG	mg/l	lb/MG		Decant mg/l	% Removal	
300	2502	0	0	10.90	0.53	91	Chemicals added at same time
300	2502	15	125	10.75	0.32	94	Lime added first
300	2502	30	250	10.70	0.20	96	Lime added first
300	2502	15	125	10.90	0.75	87	$FeCl_3$ added first
300	2502	30	250	10.75	0.80	86	$FeCl_3$ added first

TABLE 34

SUMMARY OF JAR TESTS

% Rem. P	Pounds Per Million Gallons				Decant Total P (mg/1)	Jar Test No.
	Lime	Nalco 676	Nalco 675	Ferric Chloride		
99	2502	0	0	2369	.06	4
99	417	2.08	0	0	.17	2
99	417	1.67	0	0	.17	2
99	417	1.25	0	0	.18	2
99	417	1.67	0	0	.12	1
98	2502	0	0	500	.12	7
98	1668	0	0	2369	.085	4
98	417	0	1.25	0	.24	2
98	417	.84	0	0	.22	2
98	417	.42	0	0	.24	2
98	417	1.25	0	0	.17	1
97	2502	0	0	125	.165	7
97	2502	0	0	750	.15	7
97	2502	0	0	375	.14	7
97	3336	4.2	0	0	.19	3
97	417	0	2.08	0	.30	2
97	417	0	1.67	0	.28	2
97	417	0	.84	0	.34	2
97	417	0	.42	0	.32	2
97	417	2.08	0	0	.24	1
97	417	0.84	0	0	.24	1

TABLE 34 (continued)

SUMMARY OF JAR TESTS

% Rem. P	Pounds Per Million Gallons				Decant Total P (mg/1)	Jar Test No.
	Lime	Nalco 676	Nalco 675	Ferric Chloride		
97	417	0.42	0	0	0.23	1
96	2502	0	0	250	.20	9
96	1668	4.2	0	500	.29	6
95	2502	0	0	250	.35	8
95	2502	0	0	375	.37	8
95	1668	4.2	0	250	.32	6
95	1668	4.2	0	375	.32	6
95	1668	0	0	250	.60	5
95	1668	0	0	375	.56	5
95	1668	0	0	500	.53	5
95	2502	4.2	0	0	.35	3
95	334	2.08	0	0	.45	1
95	334	.42	0	0	.46	1
94	2502	0	0	125	.32	9
94	2502	0	0	0	.43	8
94	2502	0	0	125	.43	8
94	2502	0	0	0	.34	7
94	1668	0	0	125	.37	6
94	1668	0	0	125	.65	5
94	334	1.67	0	0	.53	1
94	334	1.25	0	0	.50	1
94	417	0	0	0	.65	1

TABLE 34 (continued)

SUMMARY OF JAR TESTS

% Rem. P	Pounds Per Million Gallons				Decant Total P (mg/1)	Jar Test No.
	Lime	Nalco 676	Nalco 675	Ferric Chloride		
93	2502	0	0	500	.47	8
93	2502	0	0	0	.33	4
93	334	.84	0	0	.56	1
91	2502	0	0	0	.53	9
91	1668	0	0	0	.99	5
91	208	0	0	0	.45	4
89	1668	0	0	0	.69	6
89	1668	4.2	0	0	.76	3
87	2502	0	0	125	.75	9
86	2502	0	0	250	.80	9
86	1668	0	0	0	.67	9
70	834	4.2	0	0	2.10	3
41	417	4.2	0	0	4.10	3

TABLE 35

CHEMICAL COMBINATIONS AND
PERCENT REMOVALS ATTAINED

Number of Chemical Combinations	Percentage Pemoval of Total Phosphorus
5	99
6	98
11	97
2	96
10	95
9	94
3	93
3	91
2	89
1	87
2	86
1	70
1	41

The jar tests indicate that the required removal of phosphorus can be attained with lime additions. Slightly better effluents were attained when ferric chloride was used in conjunction with lime. No marked reductions in lime were observed to be possible when ferric chloride was added. In some instances it appeared that good removals of phosphorus were possible when NALCO 676 was used in conjunction with reduced quantities of lime. It was, however, not possible to always attain the required removal of phosphorus when using reduced quantities of lime and NALCO 676. Very good removals of phosphorus were attained with NALCO 675 and reduced quantities of lime.

SECTION VII

INDUSTRIAL AND MUNICIPAL WASTES SURVEY

An extensive survey of industrial and municipal discharges was made in 1968 - 1969 in order to better comprehend the factors that might contribute to or complicate phosphorus removal, activated sludge settling, and tertiary pond operation.

Nineteen separate tests were run on samples collected from 24 sampling points at hourly intervals over a 24 hour day. The sampling points are shown in Figure 15 and listed and described in Table 36. The results from the analyses of samples are presented in Table 37.

Table 38 is presented to show the variations from the average wastewater that reaches the Fort Wayne Wastewater Treatment Plant. Table 39 and Table 40 show the pounds of suspended solids, BOD, and total and soluble phosphorus that reach the treatment plant each day. Table 41 shows the pounds of suspended solids, BOD, and total and soluble phosphorus found at the individual sampling locations.

Discussion

It is possible to consult the data in the tables and then isolate or determine sources of major contributors of the constituents. It is of interest to note that the waste flow at Location 8 was 6.4% of the average total waste flow for the past four years, and that it contained 26.1% of the average daily suspended solids received at the Wastewater Treatment Plant.

The industrial waste survey has given insight in regard to the sources of particular constituents found in the wastewater. It was a great help to the writers of the City Ordinance controlling discharges to the sewers and in guiding the establishment of rates for the treatment of particular wastes. The survey found the sources of wastes that would be detrimental to wastewater plant operation if they were received in appreciable volumes. The information gained definitely indicated that the brewing wastes should not go directly to the aeration tanks in quantities that would overload the aeration capacity.

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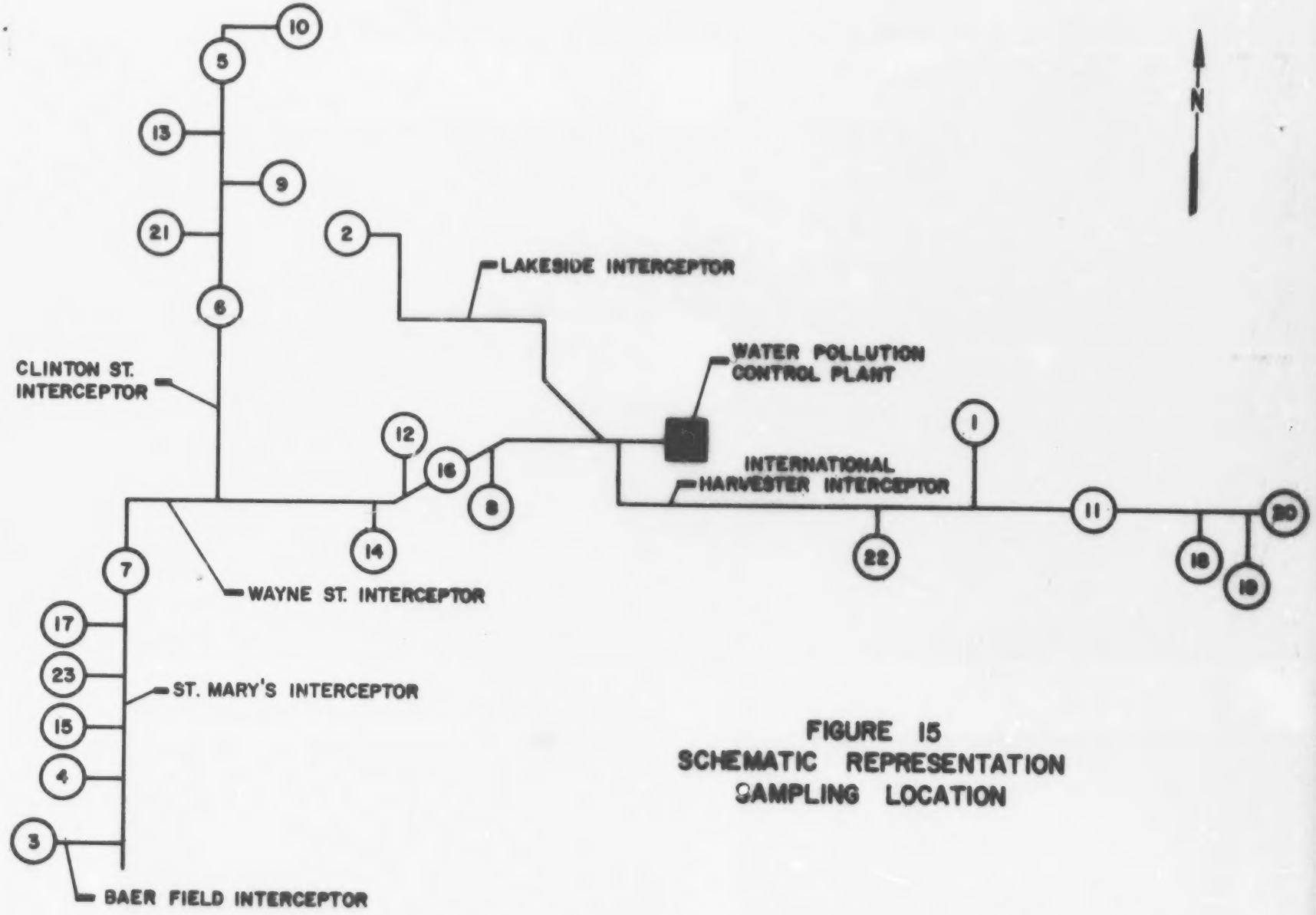

FIGURE 15
SCHEMATIC REPRESENTATION
SAMPLING LOCATION

TABLE 36

SAMPLE LOCATIONS
INDUSTRIAL WASTE SURVEY

1. SANITARY SEWER - DOMESTIC WASTES ONLY.
2. COMBINED SEWER - DOMESTIC WASTES ONLY.
3. SANITARY SEWER - DOMESTIC AND COMMERCIAL WASTES.
4. COMBINED SEWER - DOMESTIC AND COMMERCIAL WASTES.
5. INDUSTRIAL AREA SEWER - POTATO CHIP WASTES MIXED WITH DOMESTIC WASTES.
6. INDUSTRIAL AREA SEWER - BREWERY WASTES MIXED WITH DOMESTIC WASTES.
7. INDUSTRIAL AREA SEWER - CRESYLIC ACID MIXED WITH DOMESTIC WASTES.
8. INDUSTRIAL AREA SEWER - METAL PLATING WASTES MIXED WITH DOMESTIC.
9. BREWERY WASTE (2 OUTFALL LOCATIONS).
10. POTATO CHIP PROCESSING WASTE.
11. SANITARY SEWER - HEAVY INDUSTRIAL WASTE MIXED WITH DOMESTIC WASTE. INDUSTRY INCLUDES INTERNATIONAL HARVESTER COMPANY, HEAVY METAL INDUSTRY: PHELPS DODGE COPPER PRODUCTS CORP., MAGNET WIRE PRODUCTS: ZOLLNER CORPORATION, HEAVY DUTY PISTONS AND CASTINGS: MAGNAVOX CORP., TV, RADIO-PHONOGRAPH, INDUSTRIAL AND DEFENSE ELECTRONIC EQUIPMENT.
12. PRIVATE, COMBINED SEWER - PLATING WASTES, FRANKE PLATING CO.
13. DAIRY WASTE - DAIRY PRODUCTS, ALLEN DAIRY PRODUCTS.
14. PLATING WASTE -WAYNE METAL PROTECTION.
15. HEAVY LAUNDRY WASTE - (2 OUTFALLS), COVERALL RENTAL SERVICE.
16. BREWERY WASTE-(3 OUTFALLS), FALSTAFF BREWING CORP.
17. CRESYLIC ACID -GENERAL ELECTRIC CORP.
18. REFINERY WASTES.
19. HEAVY METAL WASTE -INTERNATIONAL HARVESTER CO.
20. MEAT PROCESSING WASTE -PARROT PACKING CO.
21. CARBONATED BEVERAGE WASTE -PEPSI-COLA BOTTLING COMPANY OF FORT WAYNE.
22. ROUGH RENDERING WASTES -STADLER FERTILIZER CO.
23. DAIRY WASTE - TONNE DAIRY.

TABLE 37
INDUSTRIAL WASTE SURVEY

Site	Temp	COD mg/l	BOD mg/l	pH	SS mg/l	TS mg/l	Alk. mg/l	Acidity mg/l	Phenol mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Chloride mg/l	NH_4 mg/l	Org. N mg/l	Tot. N	T. PO_4 mg/l	Yeast	Sol. PO_4 mg/l	Sol. S	Oil mg/l	Fl.Coli MPN/100	Site
1	70	212	97	7.38	102	598	277	23.3	0.03	0	0	1.08	40.8	13.1	10.0	23.2	38.1	18.8	15.2	4.8	0	49.0	1
2	66	146	77	7.36	39	532	335	28.6	0.02	0	0	1.8	60.0	16.8	11.6	28.4	27.8	9.1	8.2	2.7	0	82.2	2
3	66	139	66	7.46	34	457	310	21.3	0.02	0	0	1.17	49.3	15.1	9.70	24.8	33.8	11.0	23.9	7.8	0	420	3
4	63	215	102	7.32	48	56	264	37.6	0.02	0	0	1.20	43.0	30.0	13.4	20.8	46.5	16.2	31.9	10.8	0	279	4
5	70	890	577	6.81	894	1340	289	59.7	1.5	0	0	3.10	106	20.0	24.1	34.5	27.8	9.1	23.8	7.8	.01	268	5
6	71	885	736	6.25	277	1010	192	138	0.04	0	0	2.61	55.0	28.3	30.3	78.6	60.0	25.1	50.8	16.6	0.88	1710	6
7	70	317	170	8.12	174	589	316	8.0	5.52	0.24	0	3.40	104	38.3	22.3	61.6	30.1	9.8	22.9	7.8	0	7280	7
8	74	1710	746	6.70	414	1630	163	98.8	0.11	0	0	1.88	35.5	20.2	44.4	68.7	31.0	10.1	21.2	7.1	0.16	1940	8
9	75 72	840 6820	720 3890	11.5 6.69	536 1855	3360 4770	2416 381	0 89.0	0.54 0	0 0	0 0	2.80 3.00	140 54.0	5.20 6.00	1.68 184	180 0	880 25.0	91.4 8.8	82.8 13.8	58 4.2	1.8 0	17.8 20.8	9
10		5070	1880	6.43	4770	5075	165	73.4	0.16	0	0	2.10	58.8	13.9	53.2	67.3	29.8	6.7	18.9	5.2	0	68.9	10
11	84	337	152	7.56	110	546	157	14.3	0.88	0.62	0.05	1.82	30.9	8.40	20.8	29.1	23.5	7.8	6.7	2.2	0.14	748	11
12	67	120	2.6	8.22	44	980	382	0	0.8	0.2	0	2.70	40.0	1.00	1.15	2.15	1.89	.4	0.16	.86	220	73.4	12
13	83	7200	4390	6.20	271	2000	386	382	0.01	0	0	2.68	150	9.80	156	166	910	287.0	273	88.0	0	28.1	13
14	70	28	5.3	7.10	47	1250	230	68	.002	1.63	0	5.68	73.5	3.00	8.50	11.5	2.32	.8	0.30	.10	3.44	92.6	14
14.1	71	163	72	6.91	84	648	283	78.8	0.04	0	0	2.10	61.0	17.3	12.3	30.1	18.8	6.4	13.8	4.8	21.4	248	14.1
15	67	4080	980	10.7	1030	3530	1068	0	5.94	0.01	0	4.50	148	4.60	10.4	15.0	32.4	10.8	9.4	3.1	0.10	293	15
16		4840 2840	2468 1388	4.88 9.50	1022 413	4410 2240	138 219	148 0	0 0	0 0.08	0 0	1.88 0.78	40.0 20.0	18.0 7.80	28.8 28.4	186.8 47.0	31.8 22.8	15.3 7.4	25.0 2.8	5.8 .8	0 0	117 280	16
17		171	27	6.58	72	668	67	68.0	.072	4.3	0	1.10	120	3.80	18.0	13.8	115	36.9	98.5	30.8	0	283	17
18	80	24	11	9.80	14	1016	410	42.0	.005	0.16	0	1.30	8.2	3.48	1.68	5.2	0.58	.2	0.40	.13	0	134	18
19	82	316	78	7.46	150	757	111	38.2	1.78	5.4	0	4.88	58.8	14.7	28.3	45	101	33.0	70.0	22.8	0	296	19
20	68	1380	462	7.16	366	2180	284	58.4	.002	0	0	2.87	283	16.3	58.4	106	22.3	7.3	9.20	3.0	0	22.3	20
21	71	882	378	9.80	41	675	188	0	0.01	0	0	1.16	14.0	3.8	0.10	4.0	2.7	.9	2.60	.8	0	46.8	21
22	75	5600	2080	7.80	2980	4980	887	88.0	0.04	0	0	5.08	131	18.8	823	848	122	38.8	40.0	13.1	0	31.7	22
23	74	1100	726	10.2	218	1480	488	0	.088	0	0	1.58	58.8	1.28	43.86	44.8	128	44.1	27.0	8.8	0	18.2	23

TABLE 38

INDUSTRIAL WASTE CHARACTERISTICS

Location	Suspended Solids (mg/l)	BOD (mg/l)	Total Phosphorus (mg/l)	Soluble Phosphorus (mg/l)	Ratio					
					BOD S.S.	Total P/S.S. (%)	Sol. P/S.S. (%)	S.S. BOD	Total P/BOD (%)	Sol. P/BOD (%)
1	102	97	10.8	4.9	0.95	10.5	4.8	1.05	11.1	5.1
2	39	77	9.1	2.7	1.97	23.4	6.9	.80	11.8	3.5
3	34	86	11.0	7.8	2.53	23.0	7.4	.40	12.8	9.1
4	48	162	15.2	10.8	3.37	31.6	22.5	.30	9.4	6.7
5	894	577	9.1	7.8	0.65	1.0	0.9	2.43	15.8	13.5
6	277	735	26.1	16.6	2.66	9.4	6.0	0.38	3.6	2.3
7	174	170	9.8	7.5	0.98	5.6	4.3	1.02	5.8	4.4
8	414	746	10.1	7.1	1.81	2.4	1.7	0.55	1.4	1.0
9	1855	3890	91.4	9.8	2.10	4.9	0.5	0.48	3.4	0.3
10	4770	1880	6.7	5.2	0.39	0.1	0.1	2.56	0.4	0.3
11	110	152	7.8	2.2	1.38	7.1	2.0	0.72	5.1	1.4
12	44	3	0.4	0.5	0.06	0.9	1.1	16.70	18.3	16.7
13	271	4390	297.0	89.0	16.20	109.8	31.7	0.06	6.8	2.0
14	47	5	0.8	0.1	0.11	1.7	0.2	9.10	16.0	2.0

TABLE 38 (continued)

INDUSTRIAL WASTE CHARACTERISTICS

Location	Suspended Solids (mg/l)	BOD (mg/l)	Total Phosphorus (mg/l)	Soluble Phosphorus (mg/l)	Ratio BOD S.S.	Ratio Total P/S.S. (%)	Ratio Sol. P/S.S. (%)	Ratio S.S. BOD	Ratio Total P/BOD (%)	Ratio Sol. P/BOD (%)
14.1	54	72	6.4	4.5	1.33	11.9	8.3	.75	8.9	6.3
15	1030	930	10.6	3.1	0.90	1.0	0.3	1.11	1.1	0.3
16	1022	2455	10.3	9.8	2.40	1.0	1.0	0.42	0.4	0.4
17	72	27	36.9	30.5	0.37	51.3	42.4	2.70	136.8	113.0
18	14	11	0.2	0.1	0.79	1.4	0.7	1.26	1.8	0.9
19	150	78	33.0	22.8	0.52	22.0	16.2	1.92	42.4	29.2
20	366	442	7.3	3.0	1.21	2.0	0.8	0.83	1.7	0.6
21	41	379	0.9	0.8	9.24	2.2	2.0	0.11	0.2	0.2
22	2680	3050	39.8	13.1	1.14	1.5	0.5	0.88	1.2	0.4
23	215	735	44.1	8.8	3.42	20.6	4.1	0.29	6.0	1.2
Fort Wayne Wastewater:										
Year										
1968	194	171	9.8	4.7	0.88	5.0	2.4	1.14	5.7	2.7
1969	179	166	10.1	5.1	0.93	5.6	2.8	1.08	6.1	3.1
1970	177	161	9.9	4.4	0.91	5.6	2.5	1.10	6.1	2.7
1971	184	158	11.1	4.9	0.86	6.0	2.7	1.16	7.0	3.1

TABLE 39

INFLUENT SUSPENDED SOLIDS AND BOD TO
FORT WAYNE WASTEWATER TREATMENT PLANT

PERIOD	WASTEWATER FLOW MGD	SUSPENDED SOLIDS		BOD	
		mg/l	POUNDS PER DAY	mg/l	POUNDS PER DAY
1968	28.2	194	45,600	171	40,200
1969	30.7	179	45,800	166	42,500
1970	31.5	177	46,500	161	42,400
1971	30.8	184	47,400	158	40,600
Total	121.2		185,300		165,700
Average	30.3	184	46,325	164	41,425

TABLE 40

INFLUENT TOTAL AND SOLUBLE PHOSPHORUS TO
FORT WAYNE WASTEWATER TREATMENT PLANT

PERIOD	WASTEWATER FLOW MGD	PHOSPHORUS			
		TOTAL		SOLUBLE	
		mg/l	POUNDS PER DAY	mg/l	POUNDS PER DAY
1968	28.2	9.8	2310	4.7	1110
1969	30.7	10.1	2580	5.1	1305
1970	31.5	9.9	2600	4.4	1160
1971	30.8	11.1	2860	4.9	1260
Total	121.2		10350		4835
Average	30.3	10.3	2587	4.8	1209

TABLE 41

SUSPENDED SOLIDS, BOD,
TOTAL AND SOLUBLE PHOSPHORUS CONTRIBUTIONS
FROM SURVEY LOCATIONS

Location	Pounds Per Day			
	Suspended Solids	BOD	Phosphorus	
			Total	Soluble
1	41	39	4.3	2.0
2	7	14	1.6	0.5
3	13	336	4.3	30.5
4	112	377	35.4	25.2
5	1985	1230	20.2	17.3
6	3960	10500	373.5	238.0
7	11400	11100	641.0	491.0
8	6700	12100	164.0	115.0
9	425	895	21.0	2.3
10	2620	1035	3.7	2.9
11	684	945	48.5	13.7
12	27	2	0.2	0.3
13	60	965	65.4	19.6
14	21	2	0.4	0.1
14.1	112	149	13.3	9.3
15	2170	1965	22.4	6.5
16	3240	7780	23.4	2.5
17	158	6	81.1	67.0
18	15	12	0.2	0.1
19	357	186	78.5	54.3
20	69	84	1.4	0.6
21	16	148	0.4	0.3
22	697	794	10.3	3.4
23	22	74	4.4	0.1

SECTION VIII

SLUDGE BULKING STUDIES IN THE CITY WASTEWATER TREATMENT PLANT

HISTORY

The bulking of the activated sludge at the Fort Wayne wastewater treatment plant has been a great problem in recent years and, at times, has seriously interferred with plant operation. A study of possible causes of and methods to control this phenomenon was undertaken and is discussed below.

One of the best measures of the bulking conditions has been the sludge volume index test. A historical picture of the sludge settling qualities during the past 27 years as depicted by average yearly sludge volume indices has been tabulted and shown in Table 42. These average figures reflect gross long period sludge bulking periods but do not show periods of serious bulking of short duration.

It is apparent that there was a marked increase in the sludge volume index in 1960 and it remained above 120 until 1970.

If a change in settled wastewater characteristics resulted in bulking, a study of the laboratory results obtained over the years might be helpful.

The suspended solids concentrations in the raw wastewater and in the primary effluent have been tabulated to determine what effect, if any, long term trends in solids loadings might have had on the activated sludge settleability. These data, together with the percent removals for the period 1953 to 1971, are shown in Table 43.

Two points of some significance are noted in the data. These are:

1. There was a considerable increase in the concentration of suspended solids in the raw wastewater after 1963 and up to 1967.

2. The percent removal of suspended solids during primary treatment was greatly increased in the 1963 to 1967 period.

The concentration of suspended solids in the primary effluent in the period 1961 to 1967 was less than in prior years. This observation prompted a study of available data to see whether there was a change in the relative concentration of suspended solids and BOD_5 in the primary effluent to the activated sludge treatment plant. The 1953 - 1967 data in Table 44 was used for the comparison. There appeared to be considerable variation in the ratio of BOD_5 to suspended solids in the raw wastewater, but the ratio was not significantly different in the period 1960 to 1967 than in the period 1953 to 1960 when there was no bulking. There was, however, a definite increase in the ratio of the BOD_5 to the suspended solids in the primary effluent in the 1960 - 1967 period. At this point in the study, it seemed that the relationship of BOD_5 to suspended solids might have had some role in the changes in sludge volume index.

TABLE 42

SLUDGE VOLUME INDEX - FORT WAYNE

Year	Average Sludge Volume Index	Year	Average Sludge Volume Index
1945	114	1958	91
1946	96	1959	97
1947	105	1960	196
1948	77	1961	250
1949	63	1962	200
1950	50	1963	278
1951	54	1964	331
1952	80	1965	194
1953	79	1966	220
1954	79	1967	165
1955	73	1968	125
1956	75	1969	120
1957	74	1970	93
		1971	69

TABLE 43

SUSPENDED SOLIDS IN RAW WASTEWATER AND PRIMARY EFFLUENT AND PERCENT REMOVAL AT FORT WAYNE

Year	Suspended Solids (mg/l) Raw Wastewater	Primary Effluent	Percent Removal
1953	302	156	48.4
1954	280	184	34.2
1955	242	160	33.9
1956	241	181	24.9
1957	237	231	2.5
1958	226	202	10.6
1959	168	164	3.0
1960	261	182	30.0
1961	187	127	33.0
1962	228	124	41.0
1963	391	121	67.0
1964	304	145	52.0
1965	362	107	70.0
1966	349	118	66.3
1967	300	105	65.0
1968	194	117	39.7
1969	179	110	38.5
1970	177	155	12.4
1971	184 *	256 *	39.1(increase)

* 9 Months

TABLE 44

BOD_5 AND SUSPENDED SOLIDS
RELATIONSHIPS IN FORT WAYNE
RAW WASTEWATER AND PRIMARY EFFLUENT

Year	BOD_5 (mg/l)		RATIO BOD_5's.s.	
	Raw Wastewater	Primary Effluent	Raw Wastewater*	Primary Effluent*
1953	226	159	.75	1.02
1954	226	167	.81	.91
1955	205	149	.85	.93
1956	193	158	.80	.87
1957	175	163	.74	.70
1958	190	177	.84	.88
1959	176	159	1.05	.97
1960	220	186	.84	1.02
1961	220	175	1.18	1.38
1962	233	172	1.02	1.39
1963	247	171	.63	1.41
1964	244	182	.80	1.25
1965	198	144	.55	1.37
1966	203	150	.58	1.27
1967	180	130	.60	1.24
1968	171	138	.88	1.18
1969	166	136	.93	1.18
1970	161	139	.91	.90
1971	158**	153**	.86	.60

* See Table 43 for suspended solids data

** 9 Months

The part that wastewater flow to the plant might play in the changing of the sludge characteristics was not known. The average daily flows for the 1953 to 1971 period are shown in Table 45. There was a definite increase in flow in the period 1953 to 1967 and there has been a further increase in the 1968 to 1971 period. The pH of the raw wastewater, as yearly averages, is also presented in Table 45. There was a definite increase in pH in the 1962 to 1967 period.

During the 1962 to 1967 period, some spent lime sludge was added to the raw wastewater as it entered the plant and it influenced the concentration of raw wastewater suspended solids as can be seen in Table 43. The primary effluent solids during the time when spent lime sludge was being added to the raw wastewater were lower, indicating that the spent lime sludge was serving as a flocculant and improving the efficiency of the primary sedimentation process.

Based on the speculation that a change in the BOD_5/suspended solids ratio might play an important role in the sludge volume index of the activated sludge, experiments were performed by pumping primary sludge to an aeration unit and noting the resulting sludge volume index. Table 46 gives the sludge volume index figures for the five separate aeration systems of the Fort Wayne plant for a five-month period in 1967 when primary sludge was being added to the No. 1 unit only. The data reveal that the sludges in all of the units except No. 1 were bulking severely.

Table 47 shows the percent volatile suspended solids of the mixed liquors in the aerators during the same five months period used for the sludge volume index comparison in Table 46. There appeared to be no significant difference between the percent volatiles in the sludges of all systems even though the volatile solids concentration of the mixed liquor in System No. 1 was slightly lower than in most of the other systems. This may have indicated that it was not the inert portion of the primary sludge that brought about the improved settling characteristics of the sludge in the No. 1 System. Although sludge addition was effective in bringing severely bulking sludge under control, it caused some clogging difficulties with the sludge collectors of the secondary clarifiers.

Studies made by Pipes and his associates on the biologic characteristics of the plant mixed liquor indicated that there were 2,169 yeast count colonies per gram, actinomycetales were present, a significant number of bacillus were present, sphaerotilus were present in a sludge with a SVI of 346. From this study it was evident that no simple straightforward relationship between the presence of a particular filamentous organism and bulking can be demonstrated. However, if it is assumed that the excessive numbers of filamentous organisms do retard settling and compaction of activated sludge, then it is possible to select the organism responsible for bulking in each case.

TABLE 45

AVERAGE DAILY WASTEWATER FLOW
AT FORT WAYNE, INDIANA

Year	Flow (MGD)	pH
1953	17.6	7.63
1954	17.0	7.76
1955	17.6	7.65
1956	17.5	7.48
1957	18.2	7.32
1958	18.6	7.58
1959	18.5	7.39
1960	15.4	7.68
1961	13.8	7.78
1962	21.3	8.07
1963	20.3	8.37
1964	22.2	8.19
1965	22.8	8.13
1966	23.4	8.27
1967	24.8	8.23
1968	28.2	7.63
1969	30.7	7.39
1970	31.5	7.47
1971	30.8	7.49

TABLE 46

SLUDGE VOLUME INDICES WITH AND WITHOUT PRIMARY SLUDGE ADDITION TO AERATORS

1967 Month	Sludge Volume Index, Aerator Number				
	1*	2**	3**	4**	5**
January	90	253	231	259	342
February	122	305	212	297	373
March	76	270	231	267	286
April	133	311	176	203	283
May	134	291	167	184	307

* With primary sludge addition

** Without primary sludge addition

TABLE 47

VOLATILE SUSPENDED SOLIDS OF MIXED LIQUOR WITH PRIMARY SLUDGE ADDED TO UNIT NO. 1

1967 Month	Percent Volatile Solids, Aerator Number				
	1	2	3	4	5
January	52	60	60	64	66
February	51	56	58	60	62
March	60	61	63	63	64
April	60	63	61	52	63
May	65	69	65	50	70

During the first five months of 1967 summarized in Table 46, all aeration trains except the No. 1 unit were obviously bulking and difficult to control in the liquid solids separation phase. For the first two months of 1967, lime was added to the raw wastewater with no indications of aid in the settling of the bulking sludge.

THE 1968 - 1971 STUDIES

A picture of the situation in regards to sludge settling in the main treatment plant during 1968 - 1971 is given in Table 48. Besides showing months when the sludge was in a bulking or semi-bulking condition, it shows:

1. When spent lime sludge was added to the raw wastewater.

2. When no spent lime sludge was processed in the treatment plant.

3. When spent lime sludge was being added to the primary effluent.

The suspended solids concentrations in the raw wastewater and primary effluent for the 1968 - 1971 period are presented in Table 2. The figures from Table 2 were used in the calculation for the amount of lime sludge solids that were added to the influent to the aeration tanks. The calculated figures were previously presented in Table 7.

Table 49 is a presentation of BOD in the raw wastewater and primary effluent during the 1968 to 1971 period. A decrease in BOD removal during primary sedimentation in 1970 and 1971 is an indication that the spent lime sludge carries an appreciable amount of BOD, perhaps as much as 6,000 pounds per day.

Table 50 shows that the amount of spent lime sludge added to the system diluted the volatile matter from 72% to 48% from 1969 to 1971.

Table 7 indicates that during the first nine months of 1971, the average daily addition of spent lime sludge solids was 35,500 pounds. The suspended solids in the raw wastewater for the same period averaged 47,400 pounds per day. According to these figures, the spent lime sludge solids were 75% of the raw wastewater suspended solids or the lime sludge solids made up 43% of the total weight of suspended solids removed in wastewater treatment.

The amount of sludge solids wasted to the digesters in 1969 was 51,000 pounds per day. In the first nine months of 1971, the digester loading increased to 82,500 pounds per day. These figures substantiate those previously presented that between 31,500 and 35,500 pounds of spent lime sludge solids were added each day in 1971 to the activated sludge.

TABLE 48

SLUDGE VOLUME INDEX WITH SPENT LIME ADDITIONS - FORT WAYNE PLANT

Year	1967		1968		1969		1970		1971	
Month	SVI	Lime Sludge	SVI	Lime Sludge	SVI	Lime Sludge	SVI	Lime Sludge	SVI	Lime Sludge
January	233	LR	58	LR	67	NL	105	NL	64	LP
February	248	LR	63	NL	56	NL	89	LR	67	LP
March	218	NL	108	NL	104	NL	98	NL	56	LP
April	213	NL	95	NL	76	NL	81	LA	71	LP
May	209	NL	115	NL	106	NL	85	NL	60	LP
June	106	NL	128	NL	89	NL	116	LA	69	LP
July	198	LR	97	NL	97	NL	150	LA&LR	78	LP
August	155	LR	157	NL	199	NL	153	LA	79	LP
September	99	LR	187	NL	226	NL	106	LP	73	LP
October	124	LR	222	NL	192	NL	55	LP		
November	111	LR	168	NL	111	NL	43	LP		
December	66	LR	108	NL	122	NL	39	LP	___	
Average	165		125		120		93		69	
Maximum	248		222		226		153		79	
Minimum	66		58		56		39		60	

NL - No Lime Sludge to Wastewater Treatment Plant
LR - Lime Sludge to Raw Wastewater
LP - Lime Sludge to Primary Effluent
LA - Lime Sludge to some Aerators

TABLE 49

RAW WASTEWATER AND
PRIMARY EFFLUENT BOD
(mg/1)

	1968		1969		1970		1971	
	Raw	Primary	Raw	Primary	Raw	Primary	Raw	Primary
January	171	128	132	103	192	165	194	176
February	157	124	130	103	173	144	137	135
March	187	151	167	131	180	155	149	143
April	192	141	153	128	138	117	162	184
May	154	121	159	145	138	113	143	155
June	176	124	158	139	192	148	129	148
July	153	121	141	124	138	121	169	147
August	185	135	179	146	152	138	177	147
September	186	152	185	156	145	135	162	137
October	190	178	236	173	158	151	---	---
November	149	139	161	126	155	136	---	---
December	156	137	196	161	172	141	---	---
Total	2056	1651	1997	1635	1933	1664	1422	1372
Average	171	138	166	136	161	139	158	153
Removal	19.3%		18.1%		13.7%		3.2%	

TABLE 50

RAW SLUDGE AND WASTE
ACTIVATED SLUDGE VOLATILE SOLIDS

	Raw Sludge Total Volatile Solids (%)						Waste Sludge Volatile Solids (%)				
	1966	1967	1968	1969	1970	1971	1967	1968	1969	1970	1971
January	37	42	43	67	75	59	53	52	67	79	55
February	43	43	60	65	49	57	54	60	62	66	58
March	56	59	69	72	61	56	59	73	76	70	52
April	63	56	65	67	63	53	60	70	70	66	50
May	43	63	66	65	52	44	67	73	71	50	44
June	34	66	62	59	55	45	68	67	64	46	43
July	32	52	63	61	46	43	68	66	--	50	41
August	35	37	64	72	54	49	--	67	79	51	47
September	37	37	69	71	50	49	47	73	78	44	44
October	42	40	72	71	44	--	50	75	78	43	45
November	44	40	71	71	53	--	--	72	74	43	--
December	42	39	71	75	46	--	--	74	79	46	--
TOTAL	508	574	775	816	648	455	526	822	798	654	479
AVERAGE	42	48	65	68	54	51	59	68	72	54	42

PILOT PLANT SLUDGE SETTLING

The operation of the pilot plant units during the phosphorus removal studies was complicated by the serious bulking of the sludges. The sludge volume indices of the sludges in the pilot plant during the studies are shown in Table 9, Table 14, and Table 20.

During the first period of operation of the test units, identical satisfactory operation was the objective. However, the sludge volume index during this period ranged from 70 to 356 in the No. 1 unit and from 79 to 311 in the No. 2 unit. Because of these wide variations in sludge settling rates during periods when attempts were being made to operate the two pilot plant units indentically, it would be unwise to interpret pilot plant settling data when different chemicals and processes in one pilot plant unit are compared with the control unit.

During the test periods between January 12 and March 31, 1971, the sludges settled well, but this is the time of year when sludge bulking has been found to be minimal in the main treatment plant.

The pilot plant test periods between April 1 and October 25, 1971, were beset with severly bulking sludges and although the units did not behave similarly, the differences can not be safely attributed to the use or lack of procedures being followed. The chemical dosages, though high, were not in the range of the spent lime sludge additions to the main plant.

SECTION IX

TERTIARY TREATMENT POND OPERATION

The construction of the tertiary pond was delayed by financing problems and inclement weather and it was, therefore, not available for testing until September, 1971.

The tertiary pond was designed to receive all of the secondary effluent plus the excess waste given primary treatment but not secondary treatment.

In October all waste flow to the tertiary pond was chlorinated. Table 51 shows the loads to the tertiary pond for each month and the number of days when primary effluent made up part of the influent.

TABLE 51

TERTIARY POND LOADING

Month	Million Gallons Final Effluent	Million Gallons Primary Effluent	Number Days Primary Effluent Added
Oct. 1971	865.13	67.36	8
Nov. 1971	806.88	29.15	8
Dec. 1971	1020.58	131.06	9

The depth of the liquid in the tertiary pond during the three months averaged 5 feet. The retention time in the tertiary pond was therefore approximately 4.5 days.

The suspended solids, BOD, and COD concentrations were lower in the tertiary pond effluent than they were in the final effluent sent to the pond as shown in Table 52. There was no material change in the concentration of phosphorus as the waste moved through the pond. There was usually a decrease in the coliforms and fecal coliforms in the pond.

TABLE 52

TERTIARY POND PERFORMANCE

Month 1971	Suspended Solids mg/l		BOD mg/l		COD		Phosphorus mg/l Total		Phosphorus mg/l Soluble		Total Coliforms/100ml		Fecal Coliforms/100ml		Fecal Streptococci No./100ml	
	Final	Pond	Final	Pond	Final	Pond	Final	Pond	Final	Pond	Final	Pond	Final	Pond	Final	Pond
Oct.*	12	7	10	4	34	46	7.6	7.4	5.9	6.5	$132x10^3$	$130x10^3$	$15x10^3$	$20x10^3$	$6x10^3$	$5x10^3$
Nov.**	17	6	14	8	44	40	9.8	10.1	6.4	6.6	$6300x10^3$	$660x10^3$	$300x10^3$	$106x10^3$	-	-
Dec.**	50	11	28	14	68	55	7.2	7.8	4.4	5.5	$38x10^3$	$30x10^3$	$5x10^3$	$3x10^3$	-	-

* Pond Influent Chlorinated

** Pond Influent Not Chlorinated

SECTION X

SUMMARY OF DEMONSTRATION PROJECT

SUMMARY OF PHOSPHORUS REMOVAL WORK

Considerable knowledge was gained from the work on phosphorus removal conducted at the Fort Wayne wastewater treatment plant. The knowledge was not limited to phosphorus removal, but was also helpful in day to day operation of the facilities.

In comparing operation of the wastewater plant during periods of no spent lime sludge additions and with spent lime sludge additions, it appears that there was a removal of about 533 pounds of phosphorus with no spent lime sludge addition and 803 pounds when spent lime sludge wa being added. The percentage increase, though considerable, does not provide the desired degree of removal. The data collected show that 17.8 to 21.4 percent of the total phosphorus was removed when no spent lime sludge was being added and 22.2 to 32.5 percent was removed when 31,500 to 35,500 pounds of lime sludge solids were added to about 30 million gallons of wastewater. An estimated 31.5 to 37.5 tons per day of hydrated lime would be needed just to remove 50 percent of the phosphorus from Fort Wayne's average daily flow of 30 mgd.

In the elutriation studies conducted with the pilot plants, the data indicate that very little phosphorus held by the sludge was removed by the elutriation process. With acidification and elutriation, there is little indication that appreciable phosphorus was stripped from the sludge by the acid treatment. This can probably be attributed to the fact that "luxury" phosphorus uptake was not achieved during aeration and the bulk of phosphorus associated with the return sludge was metabolized for cell needs and was not absorbed to the cell surfaces. However, the acid elutriation process did transfer considerable suspended solids from the return sludge to the elutriate and also caused an increased turbidity in the secondary effluent of the test unit.

The removal of total phosphorus in pilot studies, combining lime and polyelectrolytes in conjunction with the activated sludge process was 52 percent. In the tests where ferric chloride and lime were added to the activated sludge, a phosphorus removal of 75 percent was achieved. This was the highest removal attained in the pilot plant by any method of treatment, but still it was not high enough to meet the Indiana Stream Pollution Control Board requirement of 80 percent. A removal of phosphorus of 63 percent was attained with the addition of ferric chloride alone to the activated sludge pilot plant. A phosphorus removal of 69 percent was accomplished with lime [$Ca(OH)_2$] alone in one of the runs during the six-month pilot plant operational period. An overall phosphorus removal of 68 percent was attained with the addition of spent pickling acid to the activated sludge. Sludges to which chemicals were added contained a higher concentration of phosphorus, as anticipated.

There were many laboratory jar tests performed and they showed that ideally as much as 99 percent of the total phosphorus can be removed with several combinations of chemicals in Fort Wayne wastewater.

SUMMARY OF INDUSTRIAL AND MUNICIPAL WASTES SURVEY

The survey of wastes in sewers from various sections of the City revealed that the constituents of particular interest vary widely in quantity and concentration and may therefore be subject to the instigation of controls.

SUMMARY OF SLUDGE BULKING AND SPENT LIME SLUDGE ADDITION

The bulking of the activated sludge or more specifically the development of a sludge with poor settling characteristics continues to be a potential problem at the Fort Wayne wastewater treatment plant. In a review of the past history of operation of the plant, it was apparent that the suspended solids content of the wastewater may play an important role in the handling of the sludge in the system. Primary sludge solids when added to a bulking activated sludge resulted in a sludge that would settle readily and still not materially raise the percentage of nonvolatile solids in the mixed liquor.

In the experiences of controlling sludge bulking with primary sludge and spent lime sludge additions, no satisfactory method was devised that would permit the determination of an optimum amount of primary sludge or spent lime sludge solids required to ensure a good settling activated sludge. It is evident from the studies, however, that both of these sludges if added at the proper point will control the bulking of activated sludge. Spent lime sludge addition to raw wastewater is not as effective for controlling activated sludge bulking at Fort Wayne as spent lime sludge addition to the primary effluent.

The availability of spent lime sludge for control of the settling of activated sludge is apparently unlimited because the 31,500 to 35,500 pounds of spent lime sludge solids used in this project are only a portion of the amount that must be discharged from the Fort Wayne water filtration plant every day.

In the pilot plant studies, activated sludge bulking was experienced most noticeably during the warmer months of the year. The chemical dosages used in the phosphorus removal studies did not produce a sludge with good settling characteristics.

SUMMARY OF TERTIARY POND OPERATION

Preliminary results from the operation of the tertiary pond indicate that this relatively short detention pond significantly reduces residual BOD_5 and suspended solids concentrations remaining in the secondary effluent.

SECTION XI

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SECTION XII

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